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ABSTRACT

This seven-chapter publication was designed to assist administrators, architects, and engineers in understanding the functions of microprocessor-based energy management systems. The information provided can be used by these individuals to develop an energy management project, select the proper system, and accurately install the system to fit specific user needs. The chapters are: "Commitment and Need" by Charles Braswell; (2) "System Planning" by Carl Fulp and Don Holberg; (3) "System Design" by Laird Sloan; (4) "Types of Control Systems" by Dale DeHart; (5) "Sources and Costs" by Carl Fulp; (6) "Purchasing Procedures" by David Lane; and (7) "Selling the Energy Management System" by Charles Braswell. Lists of major suppliers of energy management systems and of microprocessor supplies are provided in appendices. (JN)

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An Energy Task Force Publication

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PREFACE

This publication is the revised version of the workbook used at the "Controlling Energy Through Microprocessor Utilization" seminar series developed by the Energy Task Force in 1979. The authors of this publication come from many different areas of energy management including building management, consulting, sales, engineering, and administration. For this reason, the chapters in this book offer the reader a broad-based overview of microprocessor utilization in energy management.

An APFA Seminar/Publication Advisory Committee selected the topics discussed at the seminars and chose a group of expert speakers. The speakers were responsible for developing their presentations and for writing specific chapters of the workbook text.

The Energy Task Force wishes to extend appreciation to the workbook authors and Seminar/Publication Advisory Committee. A special thanks is offered to Barbara Fatkin, the principal editor of this version.

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INTRODUCTION

This publication has been prepared to assist the administrator in understanding the functions of microprocessor-based energy management systems. The basic information presented can be used by any administrator, architect, or engineer to develop an energy management or energy conservation program. The reader will learn how to administer the energy management project, select the proper system, and accurately install the system to fit specific user needs. Many people have been intimidated by the "complexity" of microprocessors. It is the intention of this publication to unveil the mysterious microprocessor and to explain computer jargon in layman's terms. A microprocessor consists of a single electronic chip that contains logic gates for manipulating data. The microprocessor is referred to as a microcomputer when it is accompanied by support devices such as memory, input/output circuits, and magnetic tape equipment.

The primary value of a microprocessor-based energy management system is that it eliminates the waste of energy without impairing normal building functions. The high reliability and small size of microprocessor-based systems are achieved through use of solid-state microelectronic components. Microprocessor-based energy management systems are capable of performing many different building control functions.[1]

Energy management control systems for buildings became a reality in the 1970s when small sensing and control devices began to be used in computers. The evolution began 30 years ago when the transistor and the stored-program digital computer were developed. The solid-state integrated circuits developed from transistors made it possible to manufacture electronic equipment that was much smaller, less costly, and more reliable. Computers became an ideal market for the solid-state integrated circuits because digital systems require large amounts of active circuits as compared to systems such as radios having analog amplifications.

During the late 1950s and early 1960s basic integrated circuit (IC) theory was formulated and implemented. The components of an integrated circuit are made of semiconductor materials with the transistors, resistors, and diodes all being imprinted on a silicon wafer or chip.

The middle to late 1960s and early 1970s saw a movement in manufacturing capability from small scale integration to medium and large scale integration. Small scale integration refers to integrated circuits that provide only simple logic gates (electronic circuits that implement elementary logical functions), flip-flops (basic electronic circuits used to store information in digital computers), and buffers. Small scale chips usually contain no more than 10 to 20 gates.

In medium scale integration, the IC chips function as self-contained logic circuits such as counters, random-access memories, decoders, multiplexers, and shift registers. They contain from 20 to 100 gates.

Large scale integration refers to IC chips with more than 100 gates or gate-equivalent circuits. Current microprocessor chips contain the equivalent of several thousand gates on a single piece of silicon wafer.

Today's control manufacturers are continually offering more advanced and specialized equipment. There is a type of energy management system that will be of value to almost any type of building. The manufacturers have developed a full set of peripherals for their units. Peripheral devices are auxiliary input/output devices associated with the computer system, generally at the control station. Typical peripheral devices include punched card and magnetic tape equipment as well as auxiliary storage equipment such as magnetic disk and paper tape devices.

2 INTRODUCTION

Many manufacturers supply software with the energy management control system. Software refers to the computer programs whether in machine, assembly, or high-level language. Three types of software are employed: system software, command software, and applications software.

Figure 1 is an example of a microprocessor-based energy management system including:

- *The Host Computer*, which makes decisions based on information supplied to it.
- *The CRT* (Cathode Ray Tube), which is the input and output unit for communication with the entire system.
- *The Console Printer*, which provides scheduled or requested information in print.
- *The Remote Alarm Printer*, for systems that are not manned full-time. The remote printer can be located in any around-the-clock area such as central heating plant or security office.
- *The Communication Processor* serves as an interface between the central computer and the field units and manages communication between these units.
- *The Field Interface Device* (FID) is the final component. Each unit includes a microprocessor unit board.

The central building control microprocessor-based energy management system uses a microcomputer or minicomputer to monitor and control various points. Man-machine interface usually occurs in a central operations area which contains various consoles. These systems are appropriate when the facility comprises many buildings or a single high-rise with a central plant and several remote mechanical rooms; 200 or more points must be controlled; numerous optimization functions are called for; and control decisions must be based on a number of parameters and conditions as well as the series of events occurring.[2]

HVAC systems and equipment to be integrated into a central control energy management system should have capacities greater than those listed in Table 1.

Table 1 HVAC System and Equipment Applications

System Application	Capacity
Single Zone Air Handler	2,000 CFM
Single Zone Split System	2,000 CFM
Terminal Reheat Air Handler	2,000 CFM
Multizone Air Handler	2,000 CFM
Two Pipe Fan Coil System	50 Tons
Heating and Ventilating Unit	3,000 CFM
Hot Water Convector Heating System	500,000 BTUH
Steam Convector Heating System	500,000 BTUH
Steam Unit Heater System	500,000 BTUH
Chiller, Air Cooled	15 Tons
Chiller, Water Cooled	15 Tons
DX Unit, Air Cooled	15 Tons
DX Unit, Water Cooled	15 Tons
Hot Water Boiler	500,000 BTUH
Steam Boiler	500,000 BTUH
Direct Fired Furnace	500,000 BTUH
Hot Water Converter	500,000 BTUH

Table courtesy of National Electrical Contractors Association.

The advantages of the microprocessor-based energy management system over the single control units are:

- flexibility
- custom programmability
- ease of installation
- expandable
- phase installation
- cost-effectiveness.

The first stage in implementing a microprocessor-based energy management system is to recognize the need for such a program and to make a commitment to its accomplishment.

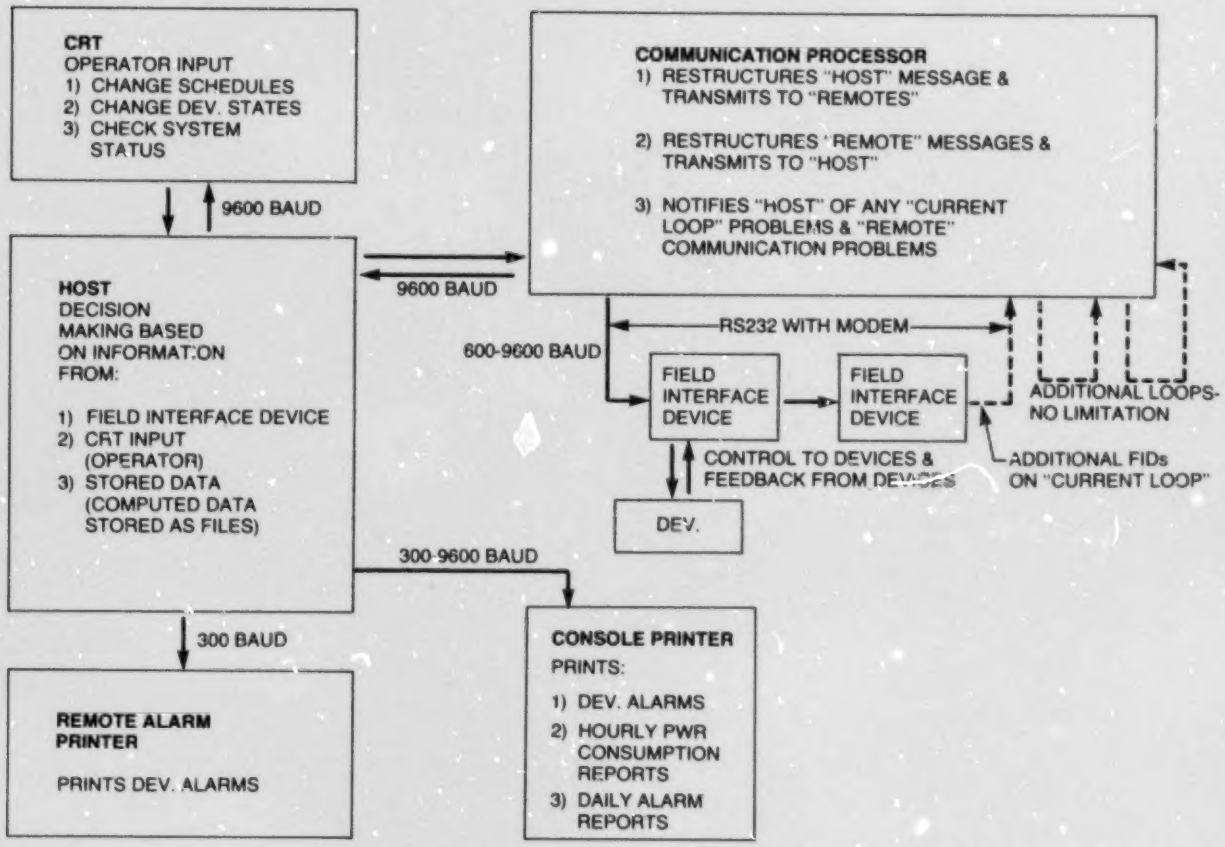

Figure 1 Block Diagram of a Microprocessor System

CHAPTER ONE

COMMITMENT AND NEED

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As a nation, the United States has moved to the forefront in industrialization, technology, and, above all, in human comfort and convenience, but the main emphasis has been on progress as envisioned by a wealth-oriented population. Perhaps many of the intended overall goals have been accomplished, but simultaneously there has been a failure in an area that is primary to these same goals. That failure has been in the field of energy. Energy production and consumption have not been kept in proper perspective; so, a need has been created — the need for conservation of energy resources. True conservation is a balance between production and consumption. That balance is the basic need, and as responsible institutions, the colleges and universities of this country must be a part of the effort to bring this balance into reality. Thus, college and university administrators find themselves in a quandary as they seek the best methods to achieve true energy conservation.

There is a secondary need, one that on many campuses may at times seem like the primary need. This second need is the conservation of money as it is related to energy consumption. Utility costs have dramatically increased causing the utility budgets to escalate. Although less energy is being used than in previous years, more money is being spent for utilities than ever before because of rising prices. On one southern campus, for example, the annual utility bill currently runs about $4 million; in 1972-73 it was approximately $1.25 million. During this period there has been no appreciable increase in floor space, and BTU consumption per square foot has decreased; yet, utility costs have more than tripled.

There is no doubt that we must conserve energy and save money. How can this be accomplished? One of the promising new developments in building energy conservation and management is the family of energy management and control systems based on microprocessors.

Of course, the first step should be the initiation of a commonsense, quick-fix program that will require little or no financial investment. The savings in energy and money are fantastic and quite astounding; however, conservation cannot be achieved by quick-fix alone.

The second step requires more sophisticated thinking about the management of controls for equipment. Today's college and university campuses have a maze of equipment (air handlers, dampers, pumps, valves, etc.) that must be regulated, adjusted, and turned on and off if energy is to be saved. The schedules and the adjustments for these controls are determined by a variety of factors such as weather, occupancy, and usage. Manual control requires someone to be at each piece of equipment at the scheduled time to make that adjustment.

For maximum conservation, when conditions in a space change, adjustments are necessary. The manpower requirements for such control are expensive, making manual control not feasible if the space conditions change more than twice per day. Thus, the alternative is some type of automation that will allow prompt adjustment.

This automation should be comprehensive in that it will perform both analog (continuously varying signal value) and digital (signals that are either on or off) routines on a real-time basis. Real-time is a situation in which a computer monitors, evaluates, reaches decisions, and effects controls within the relaxation time of the fastest loop or specified response time.

6 COMMITMENT AND NEED

The automation should eventually include central control of all equipment.

Once the decision is made to use a microprocessor-based energy management system, much groundwork is necessary, and it must begin with the full commitment of the project leader — usually the physical plant director or chief engineer who will be responsible for the entire project. During the early stages, importance of commitment may not be apparent. However, commitment can make the difference between the success or failure during any stage of development or installation of the system. Whatever the problems along the way, the project leader must persevere.

Once the basic need for an energy management system has been recognized and the director has pledged himself to the cause, it is time to plan how each facet of a somewhat momentous undertaking will be approached.

First, staff members should be involved. They should be included in the selection process. They need to understand the new system and how it will be implemented. They, too, need to be committed to the project.

Second, the director and his staff must identify energy losses created by lack of control (lighting, heating, cooling, boiler efficiency, etc.).

Third, a general determination must be made of what is to be accomplished. Details should be left for the system planning phase. At this point, the chief concern should focus on the proposed general accomplishments, which are:

- Off/on control (time control for equipment)
- Start/stop optimization
- Outdoor comfort factor calculation
- Boiler efficiency
- Chiller plant optimization
- Lighting control
- Boiler profile generation
- Water treatment
- Monitoring of equipment
- Data gathering and storing
- Other needs.

Fourth, in order for the project to succeed, it will need:

1. Commitment from higher administration — the Vice-Chancellor, the Chancellor, the President, the Board of Trustees
2. Research
3. Funding
4. Design (in-house or commissioned)
5. Bidding
6. Installation
7. Programming
8. Debugging
9. Training
10. Operating
11. Maintenance
12. Campus acceptance.

These steps should be taken in the order given as each one will simplify the one that follows it.

To gain support and commitment from higher administration, the case for the system must be properly established and presented. This may involve:

1. A look at the campus energy situation
   - Present consumption
   - Present cost
   - Rate of increase during past ten years
   - Projected consumption and rate of inflation
   - Complexity of campus.
2. That greater efficiency is provided by central control
3. A general idea of systems availabie on the marketplace
4. Personnel required to improve and continue conservation efficiency manually versus personnel required by central control
5. A "ballpark" projection of savings
6. A tentative (very generalized) approach for design and installation
7. A list of on-campus expertise that could be utilized.

A good approach would be to prepare a semiformal presentation for the Chancellor and/or Vice Chancellor. The presentation should not contain anything that cannot be substantiated. The name of

an expert who is a recognized authority in the control or computer field will add credibility to the presentation. He or she might be a faculty member, an administrative department head, or physical plant director from another campus who has firsthand experience. It is important that the expert really be an expert. Specifics on costs should not be provided at this time. Once there is general commitment to the idea, an official and in-depth investigation of system possibilities can be made.

The special presentation will probably determine whether the energy management system stops with this meeting or goes on to become a reality. Again, homework must be done. The session should be of professional quality with the dedication and commitment of those involved reflected in the presentation. Questions should be anticipated and the answers should be ready.

A commitment from the Chancellor could mean a presentation to the Board of Trustees. Whether a presentation to the board is for the purpose of obtaining authorization or is merely for public relations, it should be used to begin a selling program for the system. Once the administration has made a commitment to the energy management project, the project leader should establish a plan for developing preliminary reports and proposals.

Research measures can be developed preliminary to the systems planning phase. The information developed will serve a twofold purpose: It will strengthen the commitment and be useful later as the project develops.

The project leader should select a responsible person either in his operation or from a consulting firm to perform the research phase. The person might:

- Develop a reference file of systems available.
- Extend invitations to vendors for informal information sessions.
- Obtain a detailed description of what each system can do and how it could be utilized on the campus.
- Assemble cost data on the various systems.
- Prepare a preliminary comparison analysis of the different systems considered.
- Determine whether a pilot operation would be feasible. (But not if this would delay a permanent system installation).

The contact with vendors, consulting engineers, and other universities will provide information about a variety of installations. The project leader, the director, and selected staff personnel should visit these installations for "hands-on" experience. On these visits they should closely observe the actual operation and ask questions about design, bidding, installation, etc., and, most importantly, the success of the operation.

Reading material is available for research. A more objective evaluation of available systems can be made from this than from that provided by the sales representatives of the vendors.

The information collected from the research phase should be assembled into a package for use in future meetings and presentations. The concise but informative package should contain system descriptions, cost data of each system, cost data comparison charts, design development suggestions, and projected savings. This presentation will project a more detailed picture of the system, its operation, and the resulting benefits.

All of this research material and reports must be available to the director, the project leader, and the other committed staff. By this time each should know about the systems available, the hardware and software requirements of each system, and general information that might be unique to each.

A question that now becomes evident: "Where do the funds for this project originate?" Funding a project of this magnitude requires adeptness on the part of the project leader and the director. Initially, an estimate of the minimum funding must be made. This estimate cannot be verified until bids are taken, but it does help to establish a tentative budget so a search for funds can begin.

This search should start with the plant budget since the savings in money will be primarily there. Each year fixed amounts of funds are spent from the current operating budget for energy fuels, supplies, and equipment related to energy, and for labor to manually monitor and control energy usage. These funds will continue to be available on a continuous basis.

Another university budget to include is that of "self-supporting" operations, such as student housing. These operations are as interested as any other to minimize their costs. They may be receptive

to establishing a budget for a part of the system to serve them. In one university, the student housing administration realized payback of the cost in less than two years.

Funds required beyond this search can usually be found through the higher administration. The success for obtaining additional funds depends to a large degree upon how strong a commitment is and how thorough the communication. The administration will want to know how much money must be spent, how much can be saved, and, specifically, how the money will be used.

The process of development will be long and arduous if proper time and attention are not allowed for the research. This period is especially critical to the success of the project. There should be a subtle, but constant, supply of information and ideas to those administrators and staff who are committed to the support of the total project. Continual involvement will lead to improvements and awareness.

CHAPTER TWO

SYSTEM PLANNING

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This chapter will assist system planners in determining the need for a microprocessor-based energy management system, specifying a building automation center, and applying modular design concepts to the system.

During the establishment of a systematic approach to energy conservation based on economics of operation, it is necessary to inform and to gain support from all branches of the institution. Departments that are not informed will be skeptical of utility control modifications that may alter existing operating freedoms.

To gain departmental trust and understanding of the approach to better energy control, the study will require evaluating designs, estimating costs, and establishing whether there are benefits in central control automation. The success of any campus program for energy conservation that alters the existing operating freedoms will require the complete support of the president, vice president, and faculty.

Goals and Objectives

The goals and objectives to consider when planning a central control system are:

1. A savings of up to 30 percent of present energy units (kwh, gallons, etc.) should be the goal for the first year of operation.
2. Energy savings functions should be automatic, not manual.
3. A central control system should be able to monitor energy used hour by hour and day by day, and produce permanent records when required.
4. System control loops should be upgraded where possible, to save energy. (For example, fan system economizer cycles could be added to systems now operating on minimum outdoor air only.)
5. An ongoing energy audit on a monthly basis should be initiated when the system becomes operable. Provisions for metering will need to be made.
6. The system design should include a method of monitoring the environment for the comfort and safety of occupants.
7. The system should incorporate fire and security functions if these functions can be improved in a central control computer.
8. The system control console should be easy for nontechnical personnel to operate.
9. Dependable and prompt service maintenance is a requirement for an automation center; therefore, where the manufacturers do not have local maintenance facilities, spare parts, and service expertise, on-campus facilities and expertise must be provided.

Steps to a Successful Plan

Before a microprocessor-based energy management system project is undertaken, a professional committee must be appointed to augment the project. Someone must be assigned to head the project, preferably the assistant director or director of the physical plant. The project leader must be knowledgeable in mechanical and/or electrical engineering and have an understanding of building mechanical and electrical systems. A design engineer should also be assigned to the professional committee. The design engineer may be an in-house engineer or a consulting engineer.

The in-house engineer would probably represent a smaller financial outlay, at least at the outset. Also, being on the staff (and payroll), he may be better

attuned to existing needs because of his proximity to the problem.

The consulting engineer if selected properly offers a broad-based experience which ensures objectivity in the design. Further, he is intent on providing good service to his client because he is in the service business and the continued success of his business depends upon satisfied clients.

The charge of the professional committee is to incorporate a total plan for a central location controls center and should include the responsibility for complete analysis of the entire campus utility system to ensure maximum energy conservation from campus generation to end use. Once the professional committee is selected, the planning process begins. If not already available, a total building survey must be prepared. A survey team made up of engineers, control system specialists, fiscal or budgetary personnel, and utility technical personnel should be appointed to prepare the building inventory. The survey should include the following data:

- building number and name
- gross floor area
- year constructed
- function(s)
- number of "points" to be monitored and/or controlled
- environmental
- fire alarm
- security
- estimated equipment cost
- estimated total cost.

All buildings should be listed on the inventory chart; however, this does not mean that all buildings will be served by the central control system. If the professional committee and campus HVAC supervisors are not familiar with the concepts and capabilities of modern building microprocessor-based energy controls, seminars and briefings should be conducted to ensure that they understand the total picture. Motivation of both supervisors and maintenance personnel is critical to the success fo the project. If maintenance and operating personnel do not understand the goals and objectives of the energy management system, problems during and after installation of the control system will always be blamed on the "darn computer."

Assessment of Needs

The survey team should consult with the controls manufacturers to obtain advice and information on upgrading present control systems and ensuring compatibility with the central control system. The survey team should conduct interviews with people who operate and maintain various energy-using systems on campus.

Operating and maintenance personnel should be asked the following questions about operating procedures of the utility systems under their control:

1. What is the general condition of HVAC equipment components such as heat exchange surfaces of coils, and condensers.
2. What are the operating problems? Under-capacity? Over-capacity? Area occupant complaints?
3. What are the maintenance problems? Operation of temperature controls? Filters? Belt and other drive? Lubrication? Pumps? Heating Systems? Chillers?
4. When and why does the system waste energy—electricity, steam, or chilled water?
5. What is the operating schedule of chillers, the method of starting and stopping the unit (manual or automatic)? What is the method for optimizing performance by operating only the machines required to maintain load and control chilled water reset?
6. What are the minimum lighting levels required for specific area requirements (offices, lobbies, hallways, dormitories, laboratories, etc.)?

The team must also have access to design and operation schedules of HVAC and control systems for each building. For example, they need to know:

1. Location and type, size and capacity of each (HVAC system, radiation system, chillers, rooftop units, etc.).
2. Operating schedule of each building.
3. Operating schedule of HVAC units.
4. Occupancy schedule of each building.
5. Temperature control sequence of operation for each system to be analyzed to determine if they are "energy obsolete." Recommend changes where control redesign is necessary.
6. Engineering study of building systems to determine which systems need updating

because they are not energy efficient (such as summer reheat, double duct, multizone) or because they lack "economizer capability."

Operating schedules for lighting should be established. Lighting designs should be reviewed to determine energy savings of other high efficiency systems, such as high pressure sodium.

Present utility rates should be reviewed, and future rates should be projected. The committee should review record rate schedules, demand charges, power factor penalties, and hour by hour demand patterns.

Conducting an Energy Audit

It may have been an energy audit that led to the decision to plan for an automation system. If this is not the case, an energy audit must be initiated as soon as possible to identify specific devices in all areas that can be controlled to save energy. This audit can be done either by physical plant engineers or by a qualified outside consultant working closely with the appropriate physical plant personnel.

The audit will uncover many potential energy savings (such as leaking steam traps or excessive illumination zones) that can be achieved without installation of an automation system.

The justification for an automation system should not include the correction of problems caused by poor maintenance procedures or improper selection of controls installed in existing buildings. If existing controls are not operating properly, the automation system may only make matters worse and lead to additional problems.

The energy audit may be expensive, but it must be done before detailed specifications for the automation system can be written. In general, adding devices to the system after it has been installed will be significantly more expensive than including them in the initial specifications. Also, the detailed energy audit will be necessary in the system design and implementation process described in Chapter 3 (System Design).

Preliminary Phased Implementation

After the establishment of the goals and the completion of the energy audit, a preliminary phased or stepwise implementation plan can be developed. One phase could be part of a building, one building in 20, two or more buildings, or an area based on gross square feet. It may be wise to establish a planning board for this phase.

The planning board (or energy advisory committee) should include representation from the academic administration, business office, physical plant engineering, and the faculty. It is obvious that physical plant and business office representatives should be included — these two units have the ultimate responsibility for the purchase and installation of the system.

The academic world should be included because they are housed in the physical spaces affected by the proposed control system. On most campuses, there are faculty members who have expertise in control systems and microprocessor applications, and their input in the planning process should be most helpful.

If members of the planning board are carefully selected, they can also evaluate bids when the system is being purchased. The planning board should develop a phased implementation plan because it is usually unlikely that funds will be available for complete installation. However, by carefully identifying major energy conservation areas from the energy audit and the goals report, the planning board can recommend a phased implementation based on funds initially available as well as anticipated funds that will accrue from energy savings. It is at this stage that preliminary savings estimates must be made by close inspection of past energy use records (i.e., the effect of demand limiting, cycling, and steam control).

Potential Energy Savings Analysis

There are several available methods for estimating dollar or energy units savings that could be realized from various conservation steps when using a central control system. These are manual calculations, computer generated savings estimate, and building simulation programs.

Manual calculations. Many savings can be easily calculated using standard engineering and pocket calculators. For example, the savings obtained by reducing ventilation air supplied to a building can be manually calculated as shown by the following example:

A 100,000 square foot three-story building, 50,000 cfm air handling capacity. Electrical cost $.04 per kwh, 50 HP fan system, 15 percent ventilation air, occupied 8:00 a.m. through 8:00 p.m., five days per

week, currently running 6:00 a.m. through 10:00 p.m., five days per week.

16 operating hrs/day
− 12 occupied hrs/day
− 1 hr start-up/day

3 hrs saved/day

3 hrs/day × 5 days/week = 15 hrs/week saved

15 hrs/week × 52 weeks/yr × .8 kw/HP × 50 HP = 31,200 kwhs/yr

31,200 × .04 $/kwh = $1248.00 saved/yr

In addition to electrical savings, there will be additional heating and cooling energy savings such as fresh air supply being shut off.

Computer program estimate. There are numerous computer programs that can be used to estimate savings that might be obtained from various conservation steps all the way from adding pipe insulation to optimizing the starting time of a HVAC system. These programs can be entered via simple input forms and do not require the service of a consultant or programmer. The cost of the programs is nominal because programs and output are standard, and standard assumptions are made to cover a wide range of situations. Some energy savings analysis can best be done by a building simulation technique. This involves putting the building structure, HVAC, and control parameters into a sophisticated program that can "run" the building for a complete year, using weather data typical for that area, and then print out energy usage data using various HVAC, insulation or control configurations. Costs to run such programs may run from $1000 and up.

At this point, a preliminary decision should be made concerning communications. It may be that a simple time clock or demand limiter would be appropriate for some buildings while others require direct communication with the physical plant control center.

Conduits for locally installed communication wiring can then be identified or the telephone company can provide estimates of communication costs. In some cases, unused wire pairs in an existing monitoring cable can be identified as available for use in the centralized control system. Unless special wire is required by a particular vendor for high speed transmission, twisted shielded pairs are satisfactory. Systems are now available that can accommodate communication up to 64 buildings on one loop of voice-grade wires. Of course, the size of the buildings would determine how many are on a loop. In the worst case, per month costs for communication should not exceed the cost of an additional telephone in each building.

If the professional committee has recommended a distributed system with host control computer and individual building control units, the report to the administration from the planning board should be a priority list of buildings including the following information for each:

Monitoring
- Digital Inputs
- Temperature Inputs
- Pulse Inputs
- Other Analog Inputs

Control
- Digital Outputs
- Analog Outputs

At this point, it is not necessary to be specific as to temperature ranges, ac or dc outputs, etc. If the report is approved, it will be submitted to the survey team which will then provide the details. In addition, the planning board should make recommendations on the priority of host computer control and reporting functions. There are many "nice to have" but not essential features that can be deferred for installation at a later date. The planning board report should be a phased implementation plan that can be used by the implementation team as an outline and guide for writing the detailed specifications.

Each of the buildings identified during the goals stage must be carefully analyzed to determine what specific control and monitoring functions are needed. The following example illustrates the level of detail that should be included.

Martin Hall is of contemporary design, utilizing poured-in-place concrete in combination with precast, prestressed concrete. Exterior walls are brick with aluminum fixed sash windows, hopper openings at top and bottom. Heating and cooling are combined in a single duct variable volume system with reheat. Ten zones are provided, five for office areas and five for laboratory and classroom areas. Chilled water is provided by a centrifugal chiller with one pump supplying chilled water to all air handlers. Heat is supplied from a steam to water converter with a single pump feeding hot water to all terminal boxes. Domestic hot water is supplied by a steam to water converter with a pump for continuously circulating water throughout the building. The building has one

passenger elevator. Electrical service is provided through the campus underground distribution system. The main distribution panel, motor control center, and telephone service equipment are all located in the main mechanical room in the basement.

The first step is to list all monitoring and control points in the building (see Table 2). All the devices in the building are listed in Table 2 and described as in the following example:

Device 01 - AHU No. 1
This is a 25 HP air handler supplying conditioned air to Zone 1 (refer to Figure 2). AHU No. 1 is located in Room 252, Martin Hall. The potential power savings is 24 kw.

Table 2 Devices in the Building

NO.	DESCRIPTION	DEMAND	CYCLING	MONITORING	SHUTDOWN	CONTROL	NOTES
01	AHU #1	•	•		•		Zone 1 AHU
02	AHU #2	•	•				Zone 2 AHU
02	AHU #2						Zone 2 AHU
10	AHU #10	•	•		•		Zone 10 AHU
11	AFS #1			•			Zone 1 Air Flow Switch
12	AFS #2			•			Zone 2 Air Flow Switch
12	AFS #2						Zone 2 Air Flow Switch
20	AFS #10			•			Zone 10 Air Flow Switch
21	Temperature #1			•			Temperature Zone 1
21	Temperature #1						Temperature Zone 1
30	Temperature #10			•			Temperature Zone 10
31	Chiller						
32	Hot Water Pump				•	•	
33	Elevator			•			
34	Thermostat #1					•	Remote Set Pt. Zone #1
35	Chilled Water Pump					•	

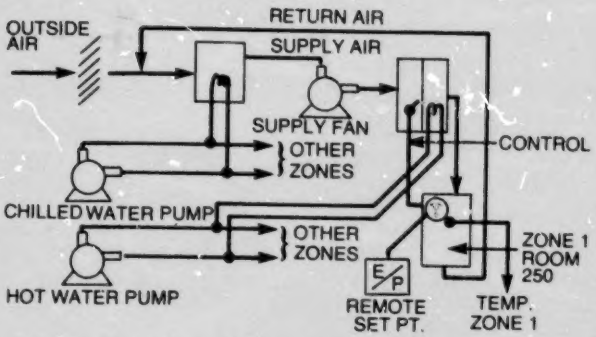

Figure 2 Block Diagram of Thermostat Control

On/off cycling is required for demand limiting, cycling, and shutdown. Control requires a single pole 120 Vac, 2 amps dry contact relay. The motor starter is located in the main mechanical room. Feedback is through Device 11, an airflow switch located in the supply duct, Room 252. This is a dry contact with closure indicating the on state, rated at 120 Vac, 1 amp. On/off control of this air handler will also be required when Device 34 remote set point thermostat for Zone 1 is changed for night setback.

Device 02 - AHU No. 2
(Description and data)

Device 03 - AHU No. 3
(Description and data)

Device 34 - Thermostat No. 1
This is a remote set thermostat located in Room 250. This thermostat controls the terminal box as indicated in Figure 2. Device 21, a thermocouple, is installed in Room 250, Zone 1 because the remote set thermostat is pneumatic and does not interface easily with the computer. The remote output from the computer should be a dc voltage signal converted to a 3 to 15 psi pneumatic signal which drives the remote set thermostat.

It is not necessary to specify a computer control law since the existing control system will tend to drive the space temperature to the new set point. This remote set feature will be used to ensure compliance with space temperatures set by various administrative directives.

If the remote set feature is to be used for evening setback of the building, the following sequence of actions must be provided by the control computer. Since this is a reheat system, simply resetting the thermostat will waste energy by driving the system as fast as possible to the new temperature. Therefore, the control computer must:

1. Reset the thermostat.
2. Turn off the chilled water and hot water pumps and the supply fan. This allows the building to coast to the new temperature.
3. When the measured temperature reaches the new value, turn on supply pumps and fan to allow system to control again.

The chilled water and hot water pumps must be provided with relay contacts rated at 250 Vac, 2 amps.

The detailed specifications for each building and point as described here are not easy to generate. However, it is important that they be given careful attention so that vendors can respond properly. In addition, this analysis will often uncover different and better ways of accomplishing the same goals. For instance, one might conclude that the use of remote set thermostats as described above to shut down the building is not warranted and simply shutting off the supply fans, chiller water, and hot water pumps is sufficient for this building.

Control System

The actual feedback control of devices is a feature of some systems now available. The increasing use of microprocessors and large scale integration of electronic devices will eventually lead to the replacement of many analog controls used today. Ultimately the computer will receive wider acceptance by architects and designers so that new systems for building control will actually be computers even if they are called "controllers." The typical application is to provide control functions that override specific automatic analog controllers. The energy management control can then reset thermostats or modify damper settings as desired to conserve energy.

Any basic feedback control system can be represented by the block diagram in Figure 3. While control systems often contain many of these interconnected loops, negative feedback is the important concept. The controlled variable must be measured and compared with some reference set point. The difference provides the controller an input on which it acts to manipulate some final control elements to change some variable in the process. Negative feedback implies that the controller output always acts in the proper direction so that the difference between measured output and set point decreases. Such a control system can act to remove the effect of load disturbances while also acting as a command controller to drive the process to a new state for a change in set point.

The point to consider is the means of interfacing to the control system. In a building with multiple remote set thermostats, it is necessary to provide a new set point signal and simply let the controller drive the area temperatures to their new state.

Alternatively, one could remove the controller output and bypass the controller completely. In this case the computer must be provided with appropriate programs to ensure negative feedback and an appropriate control law. In both cases, either the output of the measuring element or the output from a second measuring element must be provided as input to the computer. When the automation system is designed, the range and type of variables must be specified for both input and output. If the computer is to act as the controller, the type of control law must be explicitly specified. Most cases can be specified in the form of the block diagram in Figure 4.

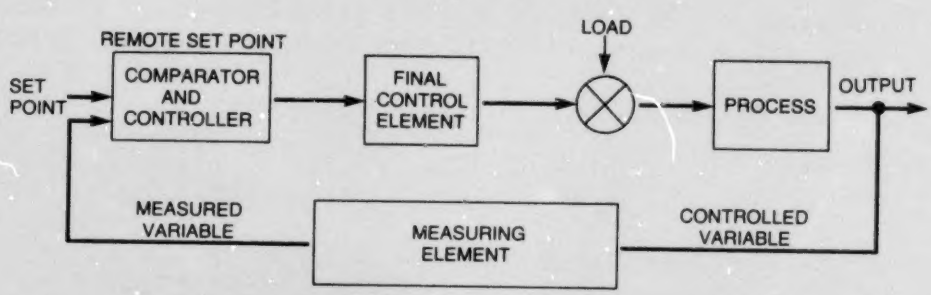

Figure 3 Block Diagram of Controller Output Reducing the Difference Between the Measured Variable and Set Point

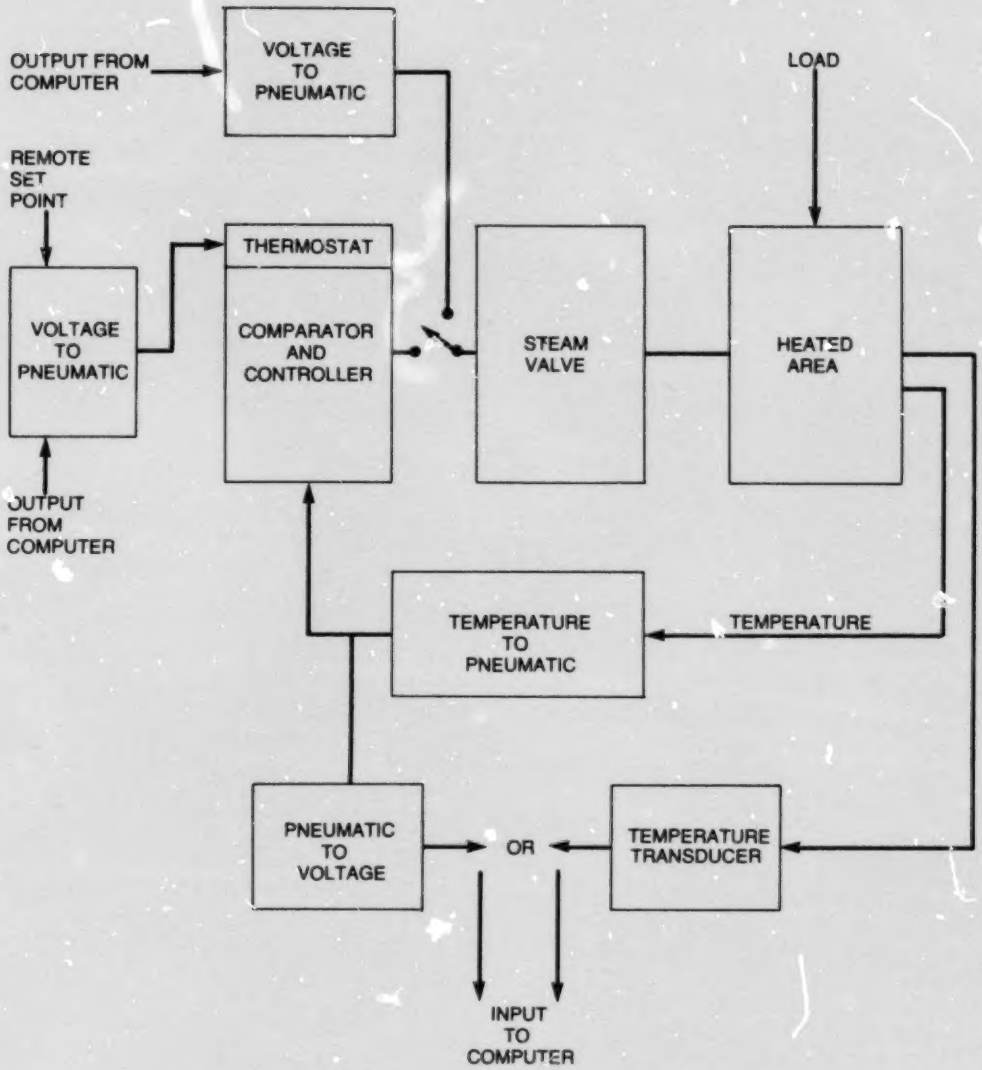

Figure 4 Block Diagram of Generalized Building Automation System

CHAPTER THREE

SYSTEM DESIGN

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System designers have been traditionally limited by equipment constraints, but microprocessor technology has extended the data gathering, control, and decision-making capability of computers. This technology, coupled with new minicomputer-based systems, frees the system designer to develop true energy control techniques. The system designer should not interpret this as total liberation from equipment constraints — rather, as a step in the continuing history of the system designer's emancipation from the bonds of equipment limitations. Let's examine this history.

History

In systems design, we can heed George Santayana who said, "Those who cannot remember the past are condemned to repeat it." There are some traditions in energy control systems design that should be perpetuated but more which should be avoided. A review of the modern age of control sets the stage for considering the various system design concepts.

Manual Control. The simplest control system is one where the operator performs the entire control function. The operator reads an instrument and takes a subsequent control action based on the reading. By periodically checking the instruments, the operator determines if the control action has the desired effect and acts accordingly.

System design for a manual system usually results from "seat-of-the-pants" engineering and rarely involves detailed analysis. The two major system design considerations are where to locate the instrumentation and what controls to use. The combination of the "human computer" and engineering experience results in an effective system.

In a manual system, each component is treated as an individual subsystem and the effects of one subsystem on another are rarely considered. Hence, the characteristics of a manual system are: (1) simple manual controls, (2) no subsystem interaction, and (3) intensive labor due to the direct human intrusion in the control process.

Feedback and Automated Control. The next evolution of control systems was a simple feedback "circuit." The feedback circuit has been used since 1900 and accounts for the majority of controls currently in use. The standard thermostat control system, the most widely-used example of a feedback circuit, is used in most buildings today.

This system operates on the theory that when instruments indicate a certain state, the same control action is always taken. The feedback circuit can be as simple as a mechanical timer that turns lights on and off or as sophisticated as a pneumatic building system.

The system design of a feedback circuit is much more complicated than that of a manual system. The type, placement, and accuracy of the instruments play an important role in the control function. Since the "human computer" is removed from the day-to-day control function, the role of system design becomes a far more important ingredient. Feedback circuits introduced the need for skilled personnel to maintain, operate, and augment the system since the control systems could be modified and "tuned" after installation for more efficient control. This increase in skill level resulted in fewer operators.

Electronic and Digital Control. The modern control function evolved from work done on World War II projects. This work, particularly that done at the Instrumentation Lab at MIT, pioneered electronic control circuitry to expand the automation of manually performed functions and especially to perform functions that a human cannot accomplish. This latter

concept has not been fully accepted by all system designers to date, particularly in the energy control area. If this concept had not been embraced in the aerospace industry, there would be no space flight, lunar landings, or reentry vehicles.

In the energy management area, electronic control began as a direct replacement for mechanical and pneumatic control systems and evolved to a central control concept where the electronic signals from the instruments to the controls were transmitted via communication lines connected to a central control area. This remote control concept radically altered the staffing and economics of total control systems, which led to the next evolution in control systems—the programmable central control system.

Programmable Central Control. Programmable central control is a recent phenomenon, available as a product for the last 15 years—and as a standard product for 10 of those years. During these 15 years, the computer required to support a programmable central control has shrunk in size from a middle-sized computer, to a minicomputer, to a combination of a minicomputer and microcomputer, or all microcomputers. These incredible technological advances happened so fast that maintenance techniques, operations, and particularly system design could not keep pace. Because of this vacuum the control system vendors stepped in to provide system design capabilities. In addition, system design efforts were confused by the fact that the computer portion of control system technology is shrouded in mystery due to jargon—bits, bytes, baud, modem, channel, interrupts, DMA, and so on. Most control system users are well versed in the HVAC instrumentation but feel uncomfortable when the subject turns to computers and the software portion of the system.

Although programmable central control systems are capable of opening new vistas in energy control, they have fallen short of some readily achievable goals. For example, since all data from all components of the energy system is available at a central point and can be processed with a powerful computer, the opportunities are limitless for optimization and control—yet the opportunities have rarely been exploited. The mystery of the computer has reduced the amount of true systems design work being done by the users. In most current systems, the user system design is only concerned with where the instruments should be located and what standardized vendor-supplied energy control techniques should be installed. The vendor performs the real system design work and, for reasons of economic necessity, only develops the energy control techniques sufficiently comprehensive to maintain a competitive position for a cross-section of all users. The control systems vendor has become the benevolent despot of the energy control function—and on occasion, not so benevolent.

Recent events have dramatically altered this situation. The energy shortage focused everyone's attention on our return for our energy dollar. One conclusion reached by some federal government energy users is that a control systems vendor's interests did not necessarily correspond with theirs. This conclusion resulted in the development of the *Interagency Guide Specification for Energy Management and Control Systems (EMCS)*, which promulgates standards for energy control systems that are installed in military installations.

Complementary to the *EMCS Specification*, many public agencies were required to produce an Energy Management Plan. Following suit, The University of Texas System Plan included a major section on specifications for energy control systems as part of their Energy Management Plan. Although different from the *EMCS* in many respects, it does give the minimum standards that The University of Texas System will accept for an energy control system. The *EMCS* and others accelerated the introduction of innovative software and display techniques and the use of microprocessors in the energy control area. These specifications allow the physical plant administrator to return to the concept of performing a systems design for energy control.

In addition, the new control systems meeting these specifications will set new standards for reliability, maintainability, and ease of operator use. Now, during the design phase for energy control systems, the user can concentrate on the energy control problem—and particularly those problems that are unique to his institution or plant—rather than the control systems hardware and software.

Microprocessor Jargon

There is a whole new set of jargon associated with microcomputers. Most of this jargon describes electronic circuitry or memory. Hence, LSI, MSI, NMOSS, MOS, SOS, and Shottky are terms related to the type of circuitry used for the microprocessor chip. Microcomputer memory jargon is more useful to the system designer. Typically the terms RAM, ROM, PROM, and EROM will be used. Random Access Memory (RAM) is the type of computer memory that can store computer programs or data and can be altered by the microprocessor. Read Only Memory

(ROM) is computer memory that the microprocessor can read but not alter. ROM is generally used to store debugged computer programs and data that is constant and never changed. In the early days of the microprocessor industry, these programs and data were recorded at the factory using a relatively cumbersome process.

PROM and EROM are special types of ROMs. Programmable Read Only Memory (PROM) means that the user (or vendor) can enter his own programs in ROM using a programming technique. ROM and PROM are often used interchangeably. Erasable Read Only Memory (EROM) consists of an "erasable" ROM circuit, meaning that the program or data is entered into the ROM circuit and read but not altered by the computer. However, using certain techniques (such as ultraviolet radiation), the original computer program and data can be erased and replaced with a new program to accommodate a new function.

Most microcomputers consist of a microprocessor, input/output circuitry, and several RAM and/or EROM modules. The computer programs are normally stored in the EROMs so that they cannot be accidentally altered, and the dynamic data (obtained from instruments), such as temperatures and pressures, is stored in RAM. The input/output circuitry communicates with instruments, computers, printers, communication lines, and other peripherals or devices.

Steps Toward A System Design

Suggesting a methodology for a system design without knowing the specifics of the individual site is a formidable undertaking, but there are several basic steps that *must* be accomplished in any system design. Each step is reviewed in the following paragraphs.

Current Operations Without An Automation System. The most neglected, ignored, and underrated portion of a system design is the analysis and documentation of the current procedures. This analysis and documentation must be performed regardless of whether or not there is any current automation system. In most sites, the system designer is a member of the physical plant staff and assumes sufficient familiarity with the current procedures. Such an assumption results in misunderstandings and errors that manifest themselves during the implementation phase of the project. The result is a compromise to the system performance, an increase in cost, or both.

The system designer must visit and personally interview the personnel responsible for current system operations. Interviews should include personnel with "hands-on" responsibility for the current energy systems as well as the applicable supervisors. The supervisor's conception of current procedures reflects "how it should be done" or "how it was done when I was directly operating the equipment," rather than how it is done now.

Questions for the interview include:

- How do you perform your job?
- What procedures do you use to control energy?
- What procedures do you use during an emergency?
- What reports, notes, memos, etc., do you produce as a result of the above procedures?
- Are there any exceptions to the above procedures or reports?
- How can automation be used to conserve energy?
- How can automation be used to make your job easier?
- How do you interact with and pass data to other operating personnel involved with the other systems?

One effective interview technique is to prepare a form including these questions and any others you can think of and send it to the person before the visit. Also, ask each person to bring a copy of every form he uses in the course of his activities. The combination of advance knowledge of the questions and discussion of the forms results in a productive and open discussion with the various personnel. It is necessary to reassure the interviewee that the visit is not part of a master plan to evaluate employee performance.

Once the interview data is acquired, it should be recorded in a written description of current procedures. Inevitably, the system designer will find gaps and inconsistencies when all data from the personnel is combined into a single narrative. Inconsistencies can be resolved by a return visit or phone call to the applicable persons. Once the narrative is consistent and complete, the system designer prepares a *Decision and Information Flow Chart.*

A Decision and Information Flow Chart illustrates procedures in an understandable and comprehensive way. The chart needs two types of figures to illustrate the process — a function block and a decision diamond. Figure 5 depicts a Decision and Information Flow Chart for a typical manual load

shedding process. It is not essential to include every detailed function or decision in the chart, particularly those associated with restoring the loads when the demand has fallen off.

It is easier to find inaccuracies or omissions in the description of current procedures using a Decision and Information Flow Chart. Often the charts point out shortcuts that are used instead of the normal procedures. By having all the interviewees review the chart and the procedures description, the systems analyst can develop a definitive description of the current system.

Current Operations With A Control System. If a control system already exists at the site, the examination of current procedures becomes a more complex process and a more important part of the whole project. Depending on the amount of equipment that can be integrated into the new system, the analysis of the existing system can save money and cut down on misunderstanding during implementation. The current procedures must be carefully examined except that, in this case, the operator of the control system plays a major role in the analysis. The vendor's operator manual provides an excellent source of the current procedures, and the operator need only be interviewed on how his actual functions differ from those in the manual. It is often found that operators use only a subset of the functions provided by the vendor and develop shortcuts to obtain needed data.

An effort must be made to determine the type of energy control programs, the location and type of sensors, the way they are described to the controlling electronics, and the means and frequency that the controlling electronics use to read the instruments and exercise the controls. This function is necessary regardless of whether the existing control system is to be integrated into the overall energy control system or if it is to be operated in parallel with the new system. If the existing system is integrated, the analysis helps determine which portions of the old system are to be incorporated into the new system. The separable pieces of a control system include: a) the instruments and controls, b) field interface devices, c) the communication cables, d) the interface to the central control system, e) the technique by which the central control system reads the instruments and exercises the controls, f) the type of central control electronics, g) the central processing unit, peripherals, system software (if the central control system is a computer), h) the energy control techniques, and i) the operator interface.

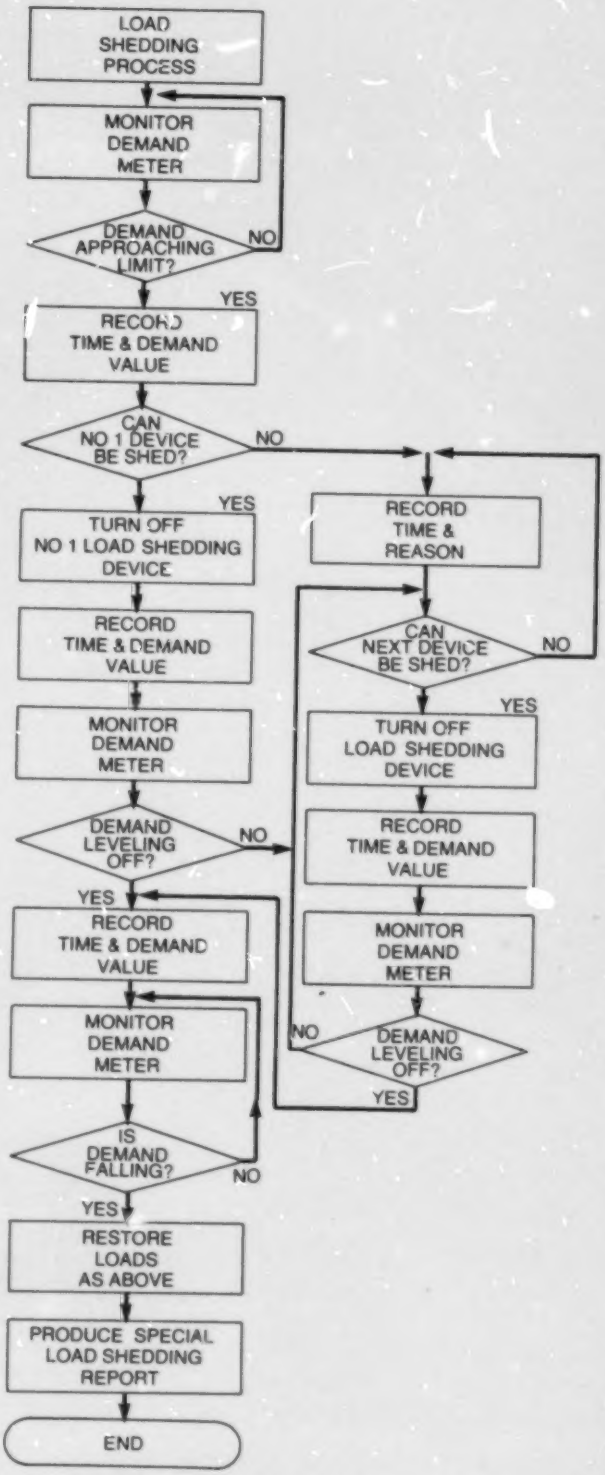

Figure 5 Decision and Information Flow Chart — Load Shedding Process

It is essential that the first three items be known if any part of the old system is to be integrated into the new system. These three items can usually be determined by inspection, by inquiries to the vendors, or by examining old purchase orders. The remaining items are not easily determined unless the controls vendor is cooperative or the system was acquired under a comprehensive purchasing agreement. In general, the interfaces, central control system, and energy control techniques are areas that the control system vendors consider proprietary. Vendors are reluctant to provide this information to protect their competitive edge, but if the system designer is part sleuth, it is possible to ferret out a great deal of the information by asking questions and by examining the vendor's documentation.

Analysis of the existing system should take place even if the new system is to be installed in parallel with the existing system. This needs to be done for self-protection, because if the incumbent controls vendor is not chosen for the subsequent implementation then his interest in supporting the existing system will wane.

Needs Analysis. The next phase in a system design is the needs analysis. This phase can be coupled with the current operations phase since the system designer calls on many of the same personnel to determine their energy management needs. The object of the needs analysis is to have everyone involved in energy management state their "druthers" as far as automation and control are concerned. Needs analysis requires considerable skill on the part of the system designer since most personnel can only state their requirements in view of what they perceive is the current state-of-the-art in control systems. The systems designer must encourage the interviewee to state his *ideal* goals. Often these ideal goals have to be tempered by the realities of existing technology, but they establish new directions and concepts for energy control.

Often when the system designer solicits ideas for energy control, the interviewee suggests techniques that are more oriented to labor savings than to the primary goal of control. These labor-saving ideas should be catalogued and considered. Often a simple adjunct to any energy control system will produce the desired labor savings and will win increased acceptance of the system.

In addition to soliciting ideas for energy management from the various personnel in his own organization, the system designer should look everywhere for new ideas — periodicals, seminars, personal contacts, government publications, and any other source he can find.

Once this data is collected, the system designer ranks the energy management concepts in order of priority. This order is influenced by the energy savings potential and may also be affected by the conceivability of implementation.

Once the energy management ideas are ranked and documented, review them with the contributing plant administration personnel. This review allows opportunity for ideas that may have emerged since the last visit and also lets the personnel know where their concepts are ranked.

Unmet Needs. The difference between the current operations and the idealized needs for energy management is the territory of unmet needs. The object of the system design is to fill as many of the unmet needs as possible within constraints of technology and funding. In the past, if the unmet needs reflected a sophisticated energy management concept, an option was to go to the major control system suppliers and determine which system came closest to satisfying the unmet needs.

If the system designer did not feel that the software programs available were satisfactory, the other option was to procure the equipment himself and launch on a project unique to his own site. This courageous approach required considerable effort, time, and money.

Today these two options are not the only choices. In fact, the various permutations and combinations of options make your head swim. These new options are a reflection of better conceived and implemented software in the central control computer — whether it be a minicomputer or microcomputer.

How can the system designer take advantage of these new ideas in control systems architecture? The most obvious way is to achieve the necessary knowledge to become an "aware" engineer.

Becoming Aware

The first thing a system designer should do is to read the aforementioned *EMCS Specification.* Reading and digesting this document demands considerable patience since it is highly technical and uses a considerable number of acronyms and abbreviations. The *EMCS Specification* demonstrates the state-of-the-art and sets standards for performance, reliability, maintainability, and operations that most vendors are capable of meeting with their latest

offerings. This is not to suggest that every system needs to have equivalent standards since some are only achieved at a high expense. The *EMCS* introduces new terminology replacing the familiar terms of the older control systems. For example, the data gathering panel is now a Field Interface Device (FID). Figure 6 illustrates a typical EMCS system configuration and its terminology.

The system designer should contact major control system suppliers for a briefing on their respective systems. Most vendors have excellent sales literature and provide an informative demonstration. During the sales briefings the system designer should remain objective and not "fall in love" with a particular system that has some appealing "bells and whistles." Some vendors have a sample Request For Proposal (RFP). Such a document will highly emphasize those aspects of the vendor's system that are particularly competitive and will scarcely mention any area in which the system is lacking. It is areas where the system is lacking that the system designer must be aware of if the vendor is considered for implementation.

The advent of the microcomputer-based system dispersed the computing power of systems and made them more modular. The system designer must be familiar with the capabilities of each module as well as the whole control system. Modularity allows

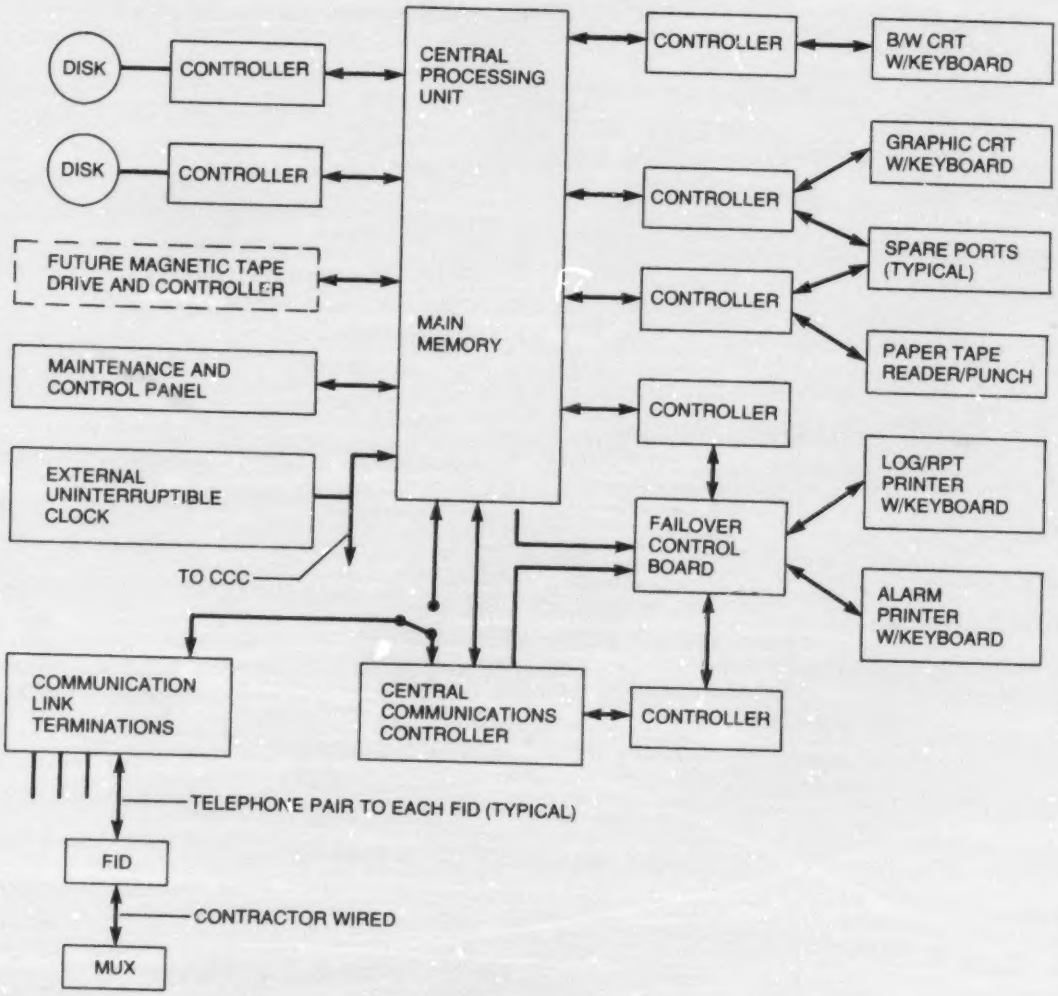

Figure 6 System Block Diagram

the system designer to build a control system a module at a time until the total system is complete. Modularity has also introduced systems using mixed vendors. This is bound to increase in the years to come.

Most control system vendors package the individual modules so that the owner cannot afford to design and implement a microcomputer-driven system. It is less costly and equally effective to use the individual modules available as standard products and use the designer's creativity in the module's software and configuration. The system designer needs to become aware of the programmability of both the central control computer and individual modules.

Again, the system designer must scour publications, attend seminars, visit vendor's plants, visit other sites, and use any other available techniques to become informed. Most of the major microprocessor vendors provide low-cost seminars. The names and addresses of the major microprocessor vendors are included in Appendix B of this publication.

The Actual System Design

The system designer is now ready to take the biggest step of all — the actual design. Most system designers are tempted to begin with this step and omit the previous ones. The resulting designs reflect their perception of what needs to be done and only occasionally lead to an effective energy control plan.

Another problem — a common trap for the system designer — is falling under the spell of a vendor. This vendor convinces the system designer that his system reflects the ultimate achievement of control system technology. The system design in this situation becomes an easy matter. In cooperation with the vendor, the system designer need only write down the offerings and performance characteristics of the "selected system," ignoring any holes in its capabilities. The vendor will be helpful in this effort, and the vendor-supplied RFP eliminates a great deal of work on the part of the systems designer. The result is known as a "wired bid" and the systems designer's employer will have a difficult time finding someone other than the "selected bidder" to respond to the RFP. Make no mistake about it: any sophisticated representative from the major control systems suppliers can tell if a bid is "wired" by glancing through the RFP.

Probably over 90 percent of the installed energy control systems were acquired by sole source procurement techniques resulting from the process described above or due to the fact that the building architect recommended the vendor. An architect depends on his selected vendor.

Ground Rules For A System Design

Starting the design is like arm wrestling an octopus — where do you begin? Should you start at the central control system and then proceed out to the field instruments, or vice versa? This decision is a matter of the designer's personal preference. It is most comfortable to start at the field end but to keep the control electronics in mind.

There are a few ground rules for the system designer to follow. For example, modern microprocessor-based control systems have dispersed processing power out to the individual buildings or portions of a building. This suggests the first ground rule: Perform as much of the processing as close to the source of the data and the controls as possible. With microprocessors as FIDs, a considerable amount of processing can be accomplished in the field. Correctly using this processing power improves the overall performances of the total energy control system. The FIDs can perform limit checking, data conversion, control actions based on limit checking and time expirations, as well as a host of other functions without communicating to the central electronics except to indicate that the function has been accomplished. Hence, the FID can now become an "exception" processing device, only communicating data to the central electronics when it is specifically requested to do so.

When the FIDs process the routine functions and report only by exception, the amount of data being routed to and from the central control system is dramatically reduced. The reduction of data makes the FID and its associated controls a more autonomous subsystem. These features are beneficial to the overall energy control system effectiveness.

Minimizing the data traffic between the FIDs and the central control system significantly reduces the data processing load on the electronics. This reduces the power of the equipment needed at central or allows it to perform more functions than previously available systems. More autonomous FIDs prevent the entire energy control system from being disabled by a single-point failure in the central control system (failing softly). Failing softly is an important design consideration and means that any single-point failure in the system should only remove some of the

system's original capabilities but not completely disable it. Autonomy is useful if the communications line between the FID and the central control electronics is interrupted. This can be a fairly frequent occurrence in a large system, particularly on a campus where construction is underway. Autonomy is also extremely useful when the central control system has to be removed from the system for various purposes such as remedial maintenance, system upgrade, or reloading of a new software release.

The amount of processing performed at the FIDs depends on the design concept of the control system vendors (assuming you are not going to design and build your own control system but are going with something standard). Most FIDs are not programmable by the user. That is, the user cannot develop and load his own energy control software programs and perform a series of functions unlike another user with the same equipment. The system designer's capability to tailor the performance of most FIDs is limited to choosing the options applicable to the situation.

The vendor develops a rudimentary executive software system and a series of communications, control, and data handling programs, usually written in the microprocessor assembly language. These programs, once debugged, will be loaded in EROM so that they can't be altered by the user or maintenance personnel. The variable parameters (limits, instrument addresses, code conversions, algorithms) are loaded in RAM where they can be easily changed by a loader (cassette) at the FID itself or by a downstream load from the central control system. Certain energy control programs such as load shedding, time event, or optimized start can be selected and loaded into the memory of the microcomputer. Programs can be added until the FID becomes a small stand-alone energy control system. This may be exceptionally useful when the FID is, in fact, a stand-alone system or is separated from the central control system by many miles.

Does the above software design sound familiar? It is identical to the central control software most systems were based on prior to the last few years. Recently, great improvements in the versatility, supportability, and user programmability of central control software has resulted. Will the same improvement take place in the software for the FIDs? Yes, but the extent of the improvement will depend on the time you implement your particular system.

The user can select a variety of peripherals for the FID. These peripherals can be so extensive that the resulting FID is a stand-alone energy control system. Depending on the location and purpose of the FID, the system designer must carefully make cost/performance trade-offs on the scope of this subsystem.

One consideration determining the scope of the FID is the minimum acceptable performance when the central control system is down or unavailable. If the system designer wishes to notify someone of alarm conditions in this situation, then this dictates alarm lights or a terminal located near the FID. There is no sense in putting alarm lights if no one is there to read them.

We can see that, although the system designer has limited options on the unique design of the software system for a FID, he has almost unlimited options for the packaged software and peripheral configurations.

Microcomputer technology has made FIDs extremely compact in size allowing them to be hidden away in a variety of locations in a building and minimizing the cable communication runs to the instruments. Nothing is quite so frustrating as to enter the equipment room of a building and see two or three FIDs mounted side by side on a wall. This means that no attempt has been made to optimize the cable runs. FIDs also eliminate the need for a HVAC configuration panel and its associated hardware and electronics in the equipment room of each building. The HVAC panel is not justifiable for maintenance reasons — the maintenance personnel should be able to test parameters using a portable terminal.

Communication Between Central Control and FID

The next area for system design consideration is the communications between the central control system and the FIDs. Again we have a general ground rule to guide our design decisions. The less the communication between the central control system and the FID — the more effective the system design. Reasons for this concept relating to increased FID autonomy have already been discussed.

Another reason for this ground rule relates to the communications technique currently being used by modern energy control system suppliers. Most systems are based on a technique where the central control system "polls" the FID. Central control periodically asks each FID over a communication line if it has anything to report. If the answer is "no," central control asks the next FID the same question and so on, until one replies "yes." The central control

then stops polling on that line and waits until the FID sends all available data before it resumes polling. A similar situation exists when central control is sending data to a specific FID. When central control's poll reaches the specific interface device it stops and passes the data to that device before resuming polling. When central control stops polling or polls another device, the FID cannot communicate with the central control system.

Most modern systems poll several communication lines simultaneously allowing them to support many FIDs. The length of time the poll stops to communicate with a field device depends upon the amount of data transmitted, the availability of control electronics to receive or send data, and the speed of the communications line between central control and the FIDs. If there is less data to communicate, then the poll need not stop quite so long. If there is less data being sent to and from FIDs, then central control is more likely to be available for communications. By reducing the amount of data we achieve a double-barrelled impact on the time the poll is stopped.

Why is it desirable to reduce this poll "stop" time? The major reason is that the shorter the "stop" time, the more FIDs we can support on a single communication line. A bad situation would exist if every FID caused the poll to stop for the maximum length of time. It is a straightforward matter to calculate how long it would be before the first device was polled again and whether this time would be intolerably long to maintain control, especially in emergency situations. It is highly unlikely that every FID would send the maximum amount of data at the same time. A more realistic situation is one in which approximately 30 percent of the FIDs are active. Maximizing the number of devices on a line means that a greater total of FIDs can be supported on the entire control system. Supporting more FIDs on a communications line results in the reduction of the cost of cable and its installation.

The third parameter affecting the time that the poll is stopped is the speed of the communications line. There is a wide range of possible speeds. Most installed systems and virtually all modern systems rely on asynchronous communications—meaning that every character transmitted on the communications line is surrounded with a start and stop bit so that the modems (electronics) recognize the differences between the characters.

Asynchronous communication is economical when data is transmitted over phone lines because of the cost of the modems on each end of the line and the lease cost of the lines themselves. The traditional asynchronous communication speeds are 110, 150, 300, 1200, and 1800 baud (or 11, 15, 30, 120 and, 180 characters/second). Most installed control systems operate at 1200 baud because that speed does not require special phone line conditioning.

This line speed is used whether the lines are directly connected to the FIDs via cables or whether phone lines are used. It was convenient for the vendors to set up systems using one communications speed. Recently, technology has evolved to produce modems (based on microcomputers) that will communicate over short distances at asynchronous communication speeds of 2400, 4800, and 9600 baud (or 240, 480, and 950 characters/second).

These modems are generally called "limited distance" or "short-haul" modems. The speed that can be used on these modems is inversely proportional to the distance the data is being transmitted. For example, 9600 baud is good for about eight miles and the slower speeds for distances greater than this. These higher speed modems will soon be incorporated in most new systems, greatly increasing the number of FIDs that may be on a single line. The higher speed line means that the poll request also takes a shorter time to travel from central control to the FIDs. The communication lines that have to go to the FIDS via phone company lines will still generally have to operate at the slower speeds. Control systems will have two types of lines, those operating at high speeds via short-haul communications lines and those operating at slow speeds using phone company lines. Most often this only requires setting the communications electronics on each line at central control.

Combining Cost-Effective Installations With Good Performance

What combination of communication lines and FIDs represents the most cost-effective installation with good system performance? The system designer does not generally have all the data at his disposal to answer this question. The most difficult information to acquire prior to formal bids is the cost of cables and installation. Even after a control systems vendor has been chosen, the communications configuration should be reviewed with the vendor's communication specialists. If the system uses several phone company communications lines, the phone company offers special computer programs that optimize the

configuration. The system can be reviewed after installation to determine if the original configuration is effective. Unless the situation is severely impacting the system performance, it is usually too expensive to make major alterations after installation, but it gives guidance on how and where additional FIDs might be added.

Communications Software And Hardware

The communications software at central control is impacted by the number of lines and the polling technique. Several vendors decided to isolate the software routines and the electronics required to interface with the communications lines into a separate computer (generally a microcomputer). The *EMCS* accelerated this trend by making this feature necessary for compliance in certain systems. A computer performing these functions is referred to as a Central Communications Controller (CCC). The major advantage of a CCC is that it relieves the central control system of the routine polling of the FIDs. Executing the polling routines and passing the data to the energy control computer programs takes up to 40 percent of a central control computer's processing power.

The disadvantage of a CCC is adding another computer into the network and often computer-to-computer interfaces are a problem. A slightly higher maintenance cost is added since two smaller computers cost more to maintain than a single larger machine. The University of Texas System allowed the vendors to bid on a separate computer for data communications or incorporate these routines in the central control system.

One special feature available with a CCC is the ability to duplicate another vendor's polling sequence. The central control system of Vendor X may be able to support the FIDs of Vendor Y, or more likely a system where some of the communications lines have Vendor X's own FIDs and the other lines are supporting Vendor Y's devices. This is accomplished by having one microcomputer poll the communication lines with one vendor's FIDs and another micro-computer poll the other vendor's FIDs. Figure 7 is an illustration of this type of configuration.

Duplicating a polling sequence could also be achieved by developing a sophisticated software routine in the central control system, but it is usually more complicated and the vendors are reluctant to attempt it. The microcomputers strip the vendor-specific data from the FIDs so that the data stream to and from the central control system is independent of

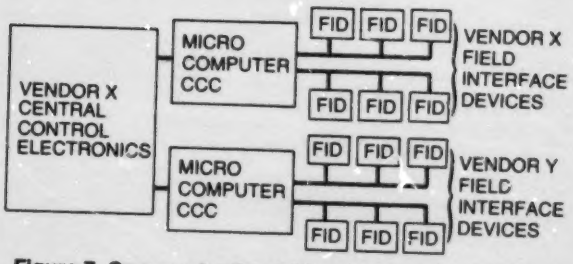

Figure 7 Communication CCCs Supporting Multiple Vendor FIDs

the type of devices (often the different types of FIDs are just different members of the product line of the central control system vendor).

Before the system designer designs a system that supports existing FIDs (installed years ago with stone-age electronics compared to today's equipment) and a variety of different vendor's FIDs, the following should be considered. Many control system suppliers are reluctant to bid on a system that has to interface to a competitor's FIDs — particularly if they are of older vintage. This reluctance is usually inversely proportional to the potential size of the order they would receive if they were successful in the bid. Most vendors will support already-installed, older versions of their own FIDs — usually with this microcomputer approach. This reluctance on the part of the major vendor opened the doors for several aggressive young system companies to make their mark in the energy control field.

The Central Control System

The system designer must consider the glamorous portion of the energy control system — the central control system. Using the word "computer" for control system has been avoided since it may consist of hard-wired electronics, a programmable computer, or in the more recent systems, a series of computers with associated peripherals. Any energy control system delivered today will include a central programmable computer that is the heart of the system. This programmable device will be a microcomputer for a small-scale system or a minicomputer with some associated peripherals for the larger systems.

The central control system can be divided into the following separable subsystems:

- computer and peripherals
- operating system software
- display and control subsystem
- application software.

Most of the control systems vendors are currently using a major minicomputer supplier for the programmable device in their energy control system. The system designer has little choice in the computer except for the computer features. The system designer should choose a memory size that is more than sufficient to include the operating system software, the communications software (if applicable), the vendor-supplied applications software, and any user-supplied application software. The other important feature is the power fail/restart and the associated software allowing the system to recover from power interruptions without the loss of data. This is particularly true if the memory of the computer is solid state rather than core (most new computers have solid-state memory).

Several other items are generally part of an energy control system computer. These include parity memory (usually a computer option that detects errors in memory), a real-time clock (essential), a programmer console, and some automatic "bootstrap" electronics for restarting the computer.

Operating System Software

The next item of concern to the system designer is the operating system software. This software, provided by the minicomputer vendor, schedules the applications software (the energy control software), operates the peripherals, passes data to the communications software and equipment, and controls the development of any additional software. This area has been filled with problems in older control systems. In the past, most of the major control system suppliers developed their own operating system software or altered the original minicomputer vendor-supplied software to such an extent that it was no longer recognizable by the original supplier. This was done to "streamline" the operating system so that it ran faster or to interface to the special equipment unique to control systems—FIDs, printer terminals and displays.

Since most operating systems are evolving as new features are added and as errors are discovered, the minicomputer vendors are constantly releasing new versions of the software to their clients. By using their own software or by modifying the minicomputer vendors' software, the control system suppliers cut themselves off from the evolutionary releases of operating system software. Most major control system suppliers recognized this fact and now use minicomputer vendor-supplied software for operating systems. The exceptions are the control system suppliers that use a microprocessor for their control system computer. Most microcomputer companies do not supply operating system software with their computers so the control system supplier is forced to develop his own.

The next ground rule for the system designer is that any minicomputer-based control system should use operating system software provided by the minicomputer vendor. In addition, the systems designer should know each control system vendor's policy on providing new releases of operating system software as they become available from the minicomputer vendor. These two items are the key to the growth and maintainability of an energy control system. Only with an operating system that is nationally supported and maintained can a user evolve a more sophisticated energy control system without being wholly dependent on the original control system supplier.

Display and Control Subsystem

The next area of concern to the system designer is the display and control subsystem. Color CRT displays were introduced and successfully integrated into energy control systems in the past few years. Color CRTs have pizazz, good operational features, and are now affordable. Most modern control systems allow the systems designer the flexibility to design the format and colors of the various graphic displays presenting data including measurement values and alarms to the energy control system operator. Some systems allow the designer to build the displays by directly communicating with the computer while the computer is performing its normal energy control functions. Building displays is useful since the system designer often makes mistakes in the format and type of data originally designed for the system. Only after operational use are these errors apparent and this capability allows them to be corrected without interrupting normal systems operations.

The CRT display design formats and keyboard-initiated display controls are an important job of the system designer. As far as the system operator is concerned, this *is* the system. The system designer must spend time in the control room subsequent to system installation. Ideas incorporated into the system subsequent to installation and based on ideas developed by operations personnel will return untold dividends in systems acceptance.

The reporting system is as important as the display system. Most reports can be user-designed and

revised, using features available in most modern energy control systems. Be aware that the reports often find their way into the hands of management and become an advertisement of the capabilities of the system.

The last important area of display and control software is the technique for manipulating the instruments and controls data. The system designer should ask, "What is the validity of the data I can obtain using the control system?" The validity depends on accuracy and timeliness. Accuracy is a function of the instruments, their locations, and the system's ability to quantify this data. Most engineers are qualified to examine these parameters and evaluate the accuracy of the system.

Evaluating the timeliness of the data is a different matter. Timeliness is often equated with the response of the system — not so! Response is a measure of the time from the entry of a request for data until data appears on the CRT screen or printer. The timeliness measures how old the requested data really is. Some systems have a very quick response but are presenting old data very quickly. To take effective control action, the system designer must base his design on the timeliness of the data and not be fooled by the promptness of the receipt of the data.

Another control software function, a motivating force behind the EMCS is the ability to add, modify, or delete new instruments and controls on the system. In the past, any system alteration was accomplished by sending a "change order" to the control system vendor. The vendor had a new software system developed at the factory, replacing the existing system. The modification cost was considerable and the required time was lengthy.

The system designer can add, modify, and delete instruments and controls while the system performs its normal operation functions in modern control systems. The operator describes any changes in the hardware configuration to the computer. The computer then reconfigures its software to accommodate this hardware configuration. The capability to modify the software and the means to achieve it should be carefully defined by the systems designer.

Applications Software

The final area to consider is the applications software (the programs actually performing the calculations to perform energy control functions). Traditionally the vendor supplies these programs for a nominal cost. Usually they are proprietary packages. The vendor supplies the programs and their description but not the logic and computer source statements in order to maintain his competitive position. These programs are typically thoroughly developed and debugged, but they suffer from the generalization necessary to make them applicable to most users.

For an idea of the industry offerings, the following list is the application software specified by The University of Texas System Energy Management Plan as routines available from potential suppliers. A description of the following optimizing functions can be found in Chapter 4 on page 42.

- Time Command Function (Start/Stop)
- Load Rotation (Duty Cycling)
- Load Shedding
- Optimum Start/Start
- Enthalpy Optimization
- Supply Air Optimization
- Supply Water Optimization
- Chiller Plant Optimization
- Boiler Plant Optimization
- Analog Limit Comparison
- Trend/Predict
- Lighting Control
- Event Initiated
- Power Factor Correction
- Dead Band and Control Point Adjustment
- Energy Totalization.

The system designer should use any routine applicable to his particular site. The system designer may want to develop application programs specifically designed to satisfy a particular site. If the system designer has done a good job of defining the operating system software and the display and control subsystem, then ideas can be readily converted to a FORTRAN computer program and incorporated as an integral part of the energy management control system. This technique is a fertile area for incorporating user-defined energy management concepts into an energy control system. The type of ideas that might be amenable to this technique are limitless — but their successful implementation depends on all factors of the system design being accomplished before the development and installation are begun.

Acceptance Testing

An important responsibility of the system designer is to develop an acceptance test. Acceptance of many systems is usually based on the vendor statement that the work is completed, and the vendor could hardly be considered unbiased in this matter.

Immediately after the system design is completed and the procurement process has commenced, the system designer should develop a scenario used for testing every aspect of the system. It is critical that unusual occurrences and error detection routines be tested. For example, the testing for power fail/restart should be done by throwing a breaker switch without any prescheduling or foreknowledge on the part of the vendor. The scenario should include every conceivable error condition and multiple operation of devices that can occur. The exact step-by-step form of the test should be published as part of the bid documents. The system should be tested at the vendor's factory prior to shipment and again after installation and commissioning. The vendor should also be made aware that payment depends on the successful completion of the tests.

As we have seen, the system designer is now capable of tuning the system, something that wasn't possible with older systems. Also, the combination of microcomputers and improved minicomputer software has introduced the possibility of user-developed software programs for energy control. These programs will become extremely sophisticated, will become tailored for the individual site, and will significantly improve the payback of the energy control system. One concept that will be extended by the introduction of microcomputer autonomy is "distributed processing" applied to multiple sites. Particularly in the university environment, the future will bring energy control systems that will handle multiple campuses, particularly where there is one major campus and multiple satellite campuses.

CHAPTER FOUR

TYPES OF CONTROL SYSTEMS

Dale DeHart
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For decades HVAC control equipment has been installed in commercial and industrial buildings to control the internal environment. The types of control systems consisted of electric, pneumatic, electronic, or a combination and were installed when there was an abundance of energy at reasonable costs. Considerable changes in methods and control techniques occurred in the 1970s, and even greater changes will take place in the 1980s. Control systems can be renovated by using present-day, state-of-the-art electric, pneumatic, solid-state, or hydraulic controls.

Control systems are divided into four main groups according to the primary source of energy:

1. *Pneumatic systems* utilize compressed air, usually at a pressure of 15 to 35 psig, as a source of energy. This is supplied to the controller, which in turn regulates the pressure supplied to the controlled device.
2. *Electric/electronic systems* utilize electric energy, either low or line voltage, as the energy source. The electric energy supplied to the controlled device is regulated by the controller, either directly or through relays or pneumatic-electric transducers. Those systems which include electronic sensing and amplification devices are generally classified as electronic.
3. *Self-powered systems* employ the power of the measured system to effect the necessary corrective action. The measuring system derives its energy from the process under control, any auxiliary source of energy.
4. *Hybrid systems* are combinations of the above which utilize multiple power sources such as electric and pneumatic, and transduce the signals to derive the benefits of both types.[3]

Control systems have very basic functions. Controls sense temperature or humidity variables and transmit those variables to a controller. The controller conditions the signal and compares it to a given set point. In turn, the controller operates a controlled device that positions a valve, damper, electric heat coil, etc. When an institution considers the selection of electric, solid-state, hydraulic, pneumatic, or a combination of electronic/pneumatic controls, each must be evaluated in terms of the total installation cost and desired long-range performance. Some major control systems are examined below to determine what retrofit techniques can be implemented to improve system performance.

Mixed Air

There are many regions of the country where the temperature and humidity are such that free cooling can be provided at different times of the year. For this reason, economizer cycles and enthalpy control systems have been added to electric, pneumatic, and solid-state control systems to improve operating efficiency. These cycles provide the necessary ventilation to meet local codes, and the enthalpy controller makes it possible to use outside air for free cooling. The enthalpy controller is located in the outside air, and in some installations it is compared to return air enthalpy conditions to determine if the damper should be under mixed air control or preset to a minimum preselected position. The minimum position can be adjusted from 0 to 100 percent enabling use of outside air for ventilation when the external conditions would add an additional burden to the cooling equipment. To further optimize the mixed air cycle, solid-state control products can be used to reset the control point of the mixed air sensor from an external variable (such as space

temperature). The mixed air would then be controlled at the highest temperature required to satisfy space conditions.

Automatic reset control of the mixed air may be added for even greater efficiency. A mixed air system will have a 10°F throttling range, meaning at a light load condition, the mixed air temperature will drift down to 50°F. By adding an automatic reset module, this wide system droop can be reduced and considerable savings realized by controlling precisely at 55°F. During light load conditions, less reheat is required to raise the mixed air temperature. Automatic reset controls, using solid-state or pneumatic devices, are added daily to mixed air control systems, chillers, makeup air units, and converters to control the temperature at setpoint. Precise setpoint control reduces operating costs inherent in wider throttling range systems and provides a typical payback of less than one year.

Heating and Cooling

Also contained in a built-up air handling unit are heating and cooling sections. A detailed evaluation of the heating and cooling section ensures that the discharge air is being controlled in the most efficient manner. To maintain the desired space environment, a sensor in the discharge air would position solid-state controls to sequence heating and cooling equipment as shown in Figure 8. Many built-up air

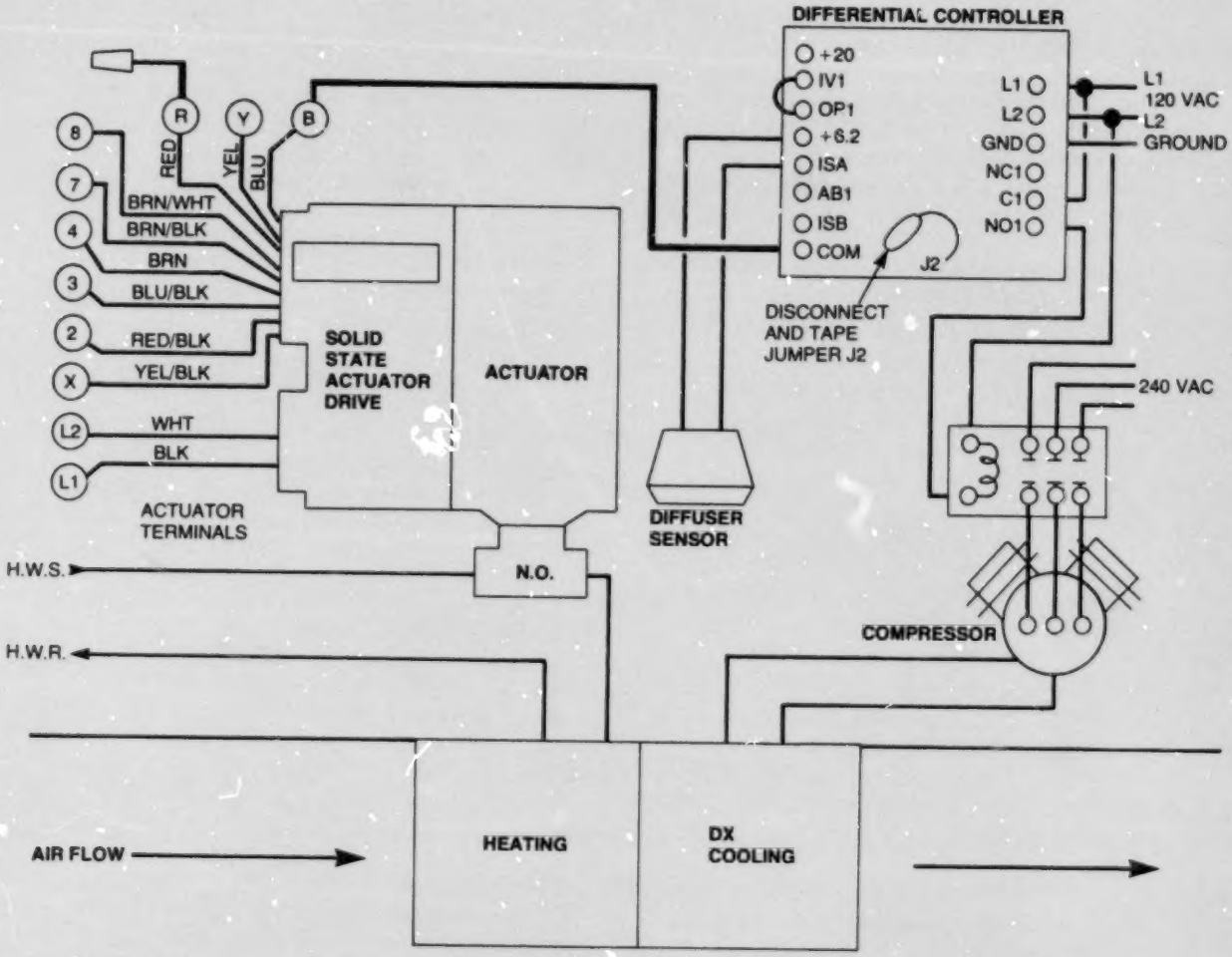

Figure 8 Solid-State Sequence of Heating and Cooling Equipment

handling units contain two-position controls or a very inefficient proportional control system. An evaluation of these systems shows that control system improvements can be realized through retrofit. Efficient operation of the heating and cooling equipment to provide a precise space environment could have a drastic effect on the performance of the central plant.

When considering retrofit possibilities in a built-up air handling system for ventilation, heating, or cooling, the physical plant administrator should use as much of the existing controls as possible. It is safe to say that approximately 80 percent of the buildings in the United States contain pneumatic control systems. Since it is costly to replace entire control systems, it may be necessary to provide hybrid systems (Figure 9), offering precise electronic sensing with pneumatic actuation. In addition, these transmitter-type signals obtained through solid-state circuitry interface more directly to computer technology to offer the physical plant director a complete facility management system. As energy conservation demand increases, these hybrid systems will be used on built-up air handling units as well as converters and boilers. They provide the best of two worlds: the accuracy of electronic sensing and computer interface capabilities with the economy of pneumatic actuation.

Packaged Systems

There are many multizone rooftop units located on the buildings of college and university campuses. The early multizone units contained electric controls that provided a fixed mixed air temperature by positioning the outside air and return air dampers. Fixed hot deck and cold deck temperatures were provided that were ultimately mixed by mixing dampers and discharge to the space. There was no interlock between the actual space environment and requirements in the hot deck, cold deck, and mixed air sections of the multizone unit. Often, as a result of improper air distribution, the hot deck and the cold deck began battling one another and consuming excessive amounts of energy in the process. An improved control system was needed to look at signals from the zone sensors and use these signals to reset the control points of the hot deck, cold deck, and mixed air sections. Pneumatic selector relays were installed so that zone controls would reset the necessary hot deck and cold deck temperatures as required by the space. This was further refined by logic-type solid-state control systems (Figure 10). These solid-state control systems control the entire multizone unit as a function of space requirements. This means that the space temperature resets the hot deck temperature to the lowest possible setting and increases the mixed air

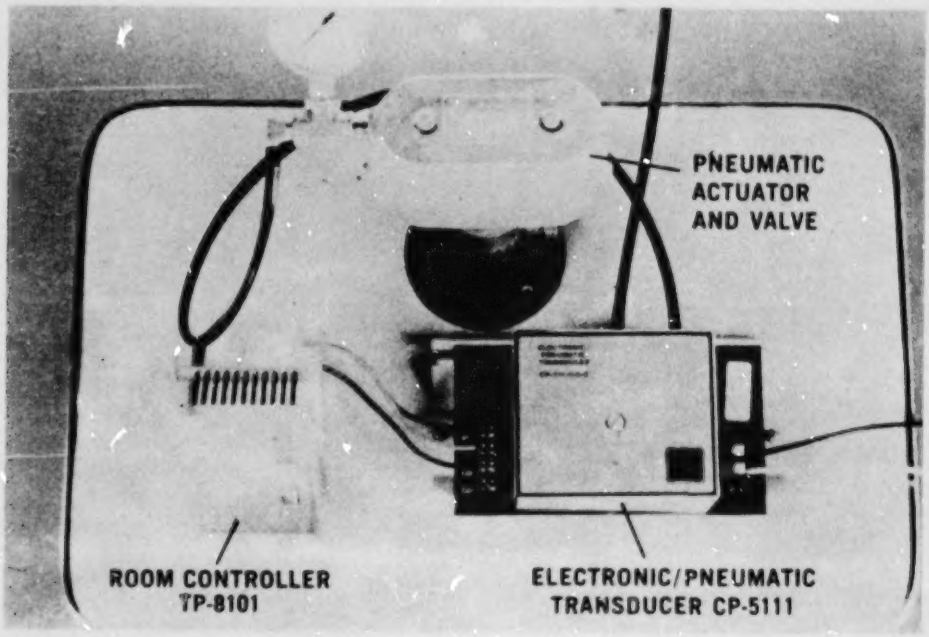

Figure 9 Solid-State Sensing/Pneumatic Actuation

temperature to its highest possible setting in the heating season. Therefore, the need to reheat the mixed air temperature was reduced. In the cooling season, the hot deck was decreased, and the mixed air temperature was reset to the lowest possible value to reduce the load on the cooling equipment. This complete solid-state logic approach offered a tremendous reduction in multizone system operating costs.

On the college or university campus, there are many single-zone rooftop units operated by two-position wall-mounted electric thermostats. These thermostats maintain space conditions through staged heating and cooling. Many single-zone rooftop units contain fixed mixed air dampers or two-position controls for outside and return air control that create additional loads on the heating and cooling equipment. To improve the operating efficiency of this type of control system, solid-state control packages have been developed that sequence the heating, ventilation, and cooling system as a function of the room thermostat (Figure 11). This system maintains space requirements and provides the most efficient operation of a single-zone roof-top unit.

Changes in operation and performance of the HVAC systems to meet energy regulation and reduce energy costs will mean that other factors must also be considered.

Optimization Systems

Night setback of the control system to obtain a 55°F temperature during the unoccupied mode will mean that the physical plant director must evaluate morning warmup cycles. A morning warmup cycle permits the inside temperature to be efficiently raised from the night setting of 55°F to the day setting of 65°F. The installation of a programmed energy saving optimizer should be considered. The optimizer accurately monitors the outside air conditions and compares them to space conditions and then starts the HVAC equipment at the exact time to reach 65°F at occupied time.

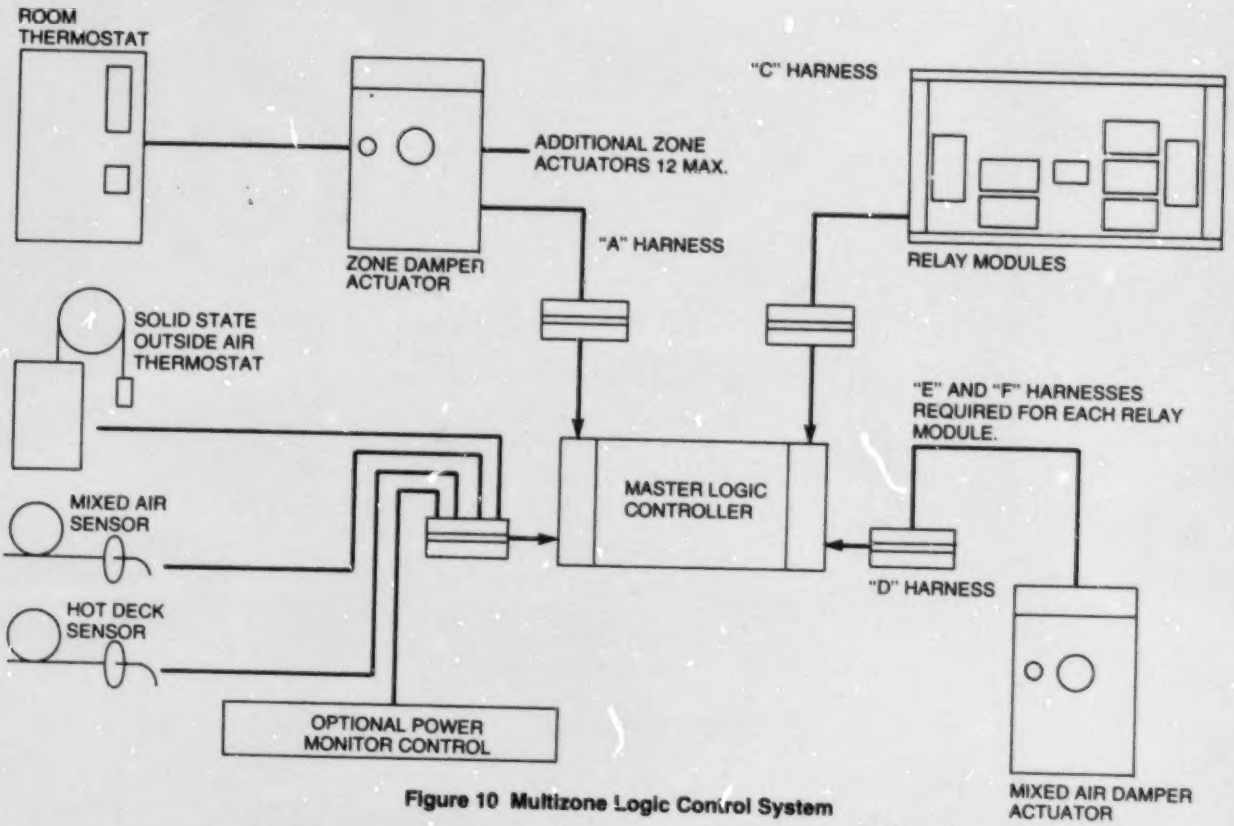

Figure 10 Multizone Logic Control System

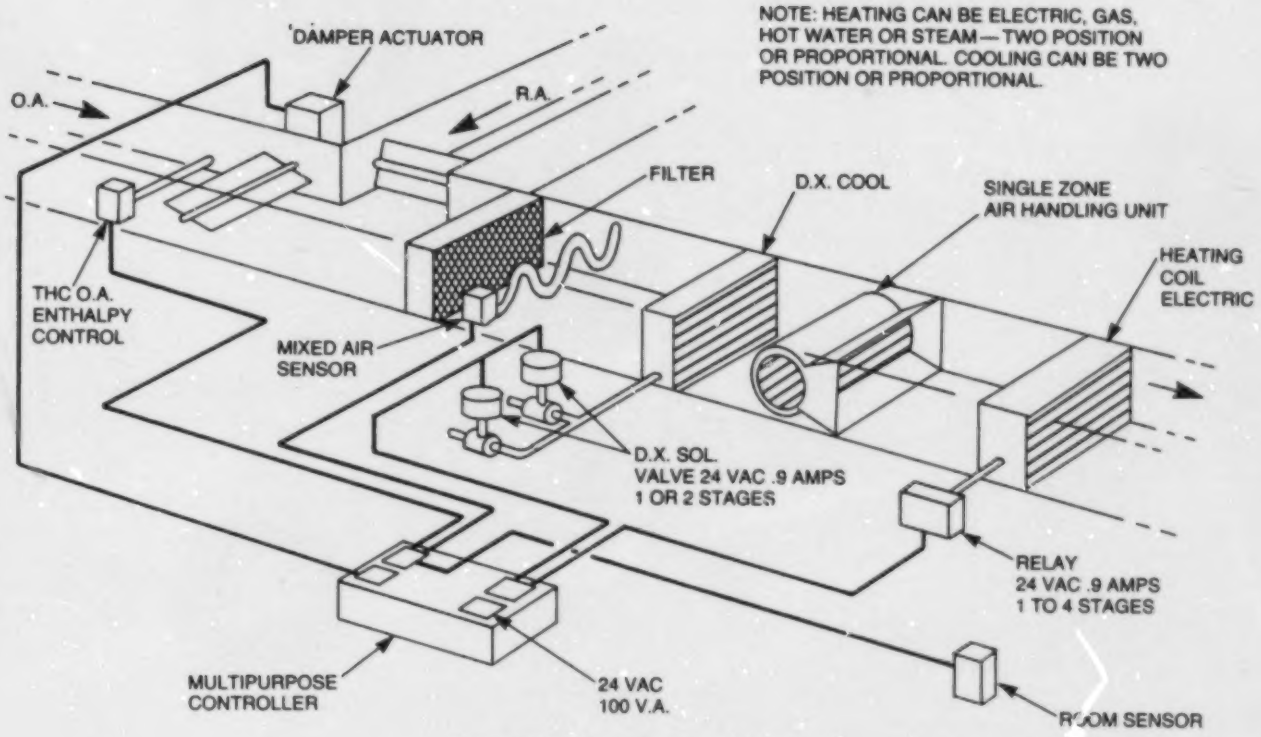
NOTE: HEATING CAN BE ELECTRIC, GAS, HOT WATER OR STEAM — TWO POSITION OR PROPORTIONAL. COOLING CAN BE TWO POSITION OR PROPORTIONAL.
DAMPER ACTUATOR
O.A.
R.A.
FILTER
D.X. COOL
SINGLE ZONE AIR HANDLING UNIT
HEATING COIL ELECTRIC
THC O.A. ENTHALPY CONTROL
MIXED AIR SENSOR
D.X. SOL. VALVE 24 VAC .9 AMPS 1 OR 2 STAGES
RELAY 24 VAC .9 AMPS 1 TO 4 STAGES
MULTIPURPOSE CONTROLLER
24 VAC 100 V.A.
ROOM SENSOR

Figure 11 Single Zone Control System

Another consideration is boiler optimization. When outdoor air reset control is added to the existing hot water converters and boilers (Figure 12), the hot water supply is controlled at the desired temperature to maintain building conditions. The outdoor reset system can be pneumatic (Figure 13), electric, or electronic. These systems will reset the supply water temperature according to a predetermined schedule. If the outdoor air is at −10°F, a 180°F water temperature might be needed to satisfy the space. However, energy will be wasted if the outdoor air temperature is 65°F, and the supply water temperature is maintained at 180°F. Reset systems will vary the supply water temperature as the outside air temperature increases to 65°F. The water temperature would be decreased to 90°F in this example. If outdoor air reset control systems are properly applied, any reset schedule can be established. Solid-state control systems for boiler optimization can be interfaced to a microprocessor building automation or facility management system. In dormitories or apartment complexes, installation of an econostat system matching the building characteristics and providing heat when required would be economical. An econostat sensor located in the outside air is calibrated to match the heat loss of the building and is compared to space temperature to provide a contact closure for operation of the boiler or valves in the zone. The closure permits hot water to circulate throughout the building. The heating source

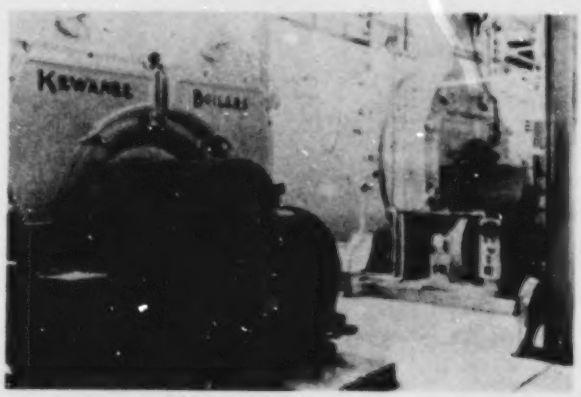

Figure 12 Boiler Optimization

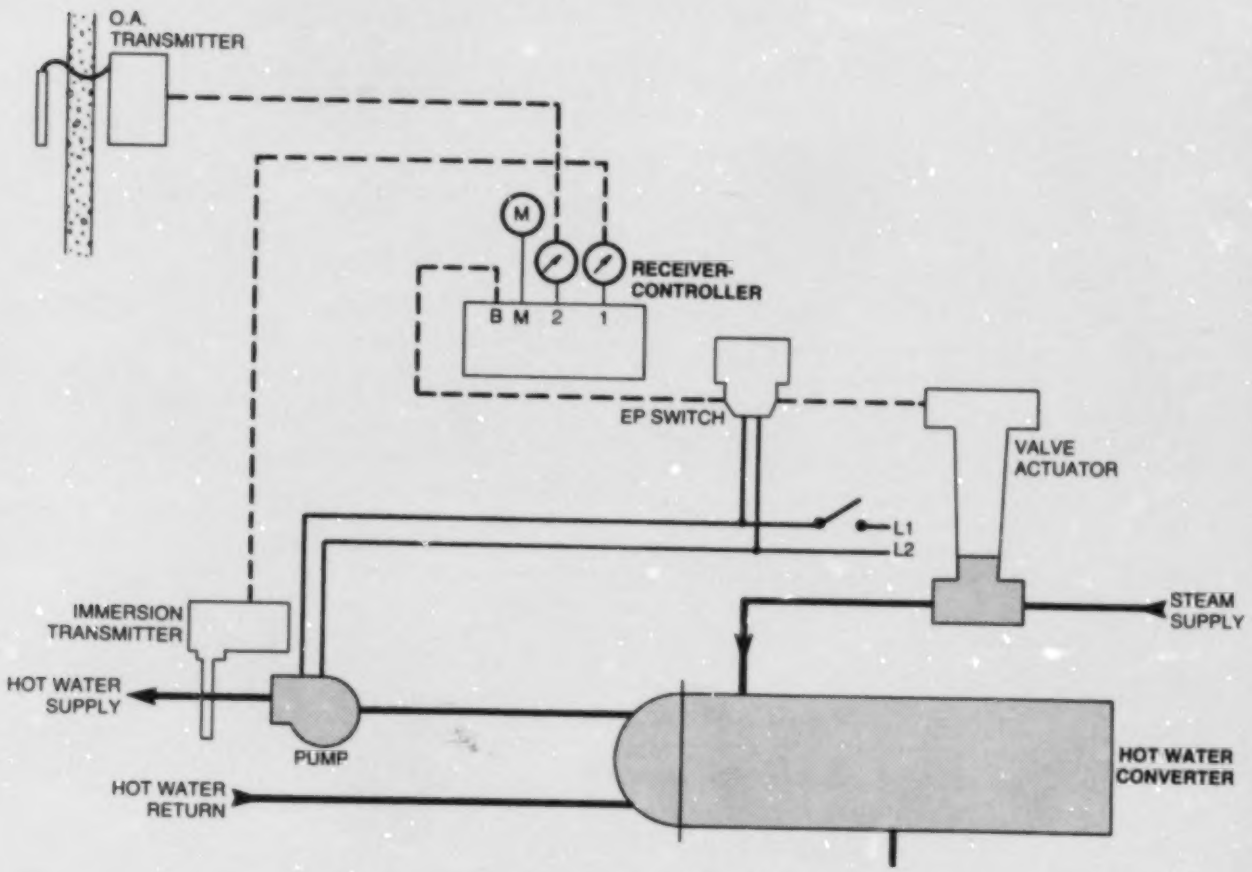

Figure 13 Outdoor Reset of Boiler or Converter

is then cycled as a function of the outside air conditions and provides heat only when required. Econostat control systems have been found to pay for themselves in a matter of months. Boiler optimization considerations include both outdoor reset and econostat control techniques.

Centrifugal chiller optimization offers significant savings in central plant operation. Chilled water optimization systems provide precise chiller control and operation. Chilled water optimization systems monitor the chilled water supply, chilled water return, and percent chiller load to precisely maintain the exact operating conditions to satisfy the building requirements. Chilled water optimization systems are installed on every manufacturer's chiller and have been operating for the past one to three years. The effect on the operation is drastic. Comparing an existing chiller control system to a chilled water optimization system (Figure 14) can be very enlightening. An evaluation of the chilled water return, the chilled water supply, and percent current shows that with an optimization system, the supply water temperature is controlled considerably higher than with an existing control system. This happens because the chilled water return sensor measures the actual building load and resets the supply water temperature upward to its highest possible level to satisfy the building. This means that with the higher chilled water supply temperature, less chilled water is required resulting in reduced costs, reduced percent load of chiller, lower kilowatt (KW) draw and kilowatt hour (KWH) usage. A good chilled water optimization system starts the chiller at a reduced load. Over time, the machine gradually loads to a point where the chilled water supply sensor takes over and maintains the exact supply water temperature required by the building. A chilled water optimization system pays for itself in months.

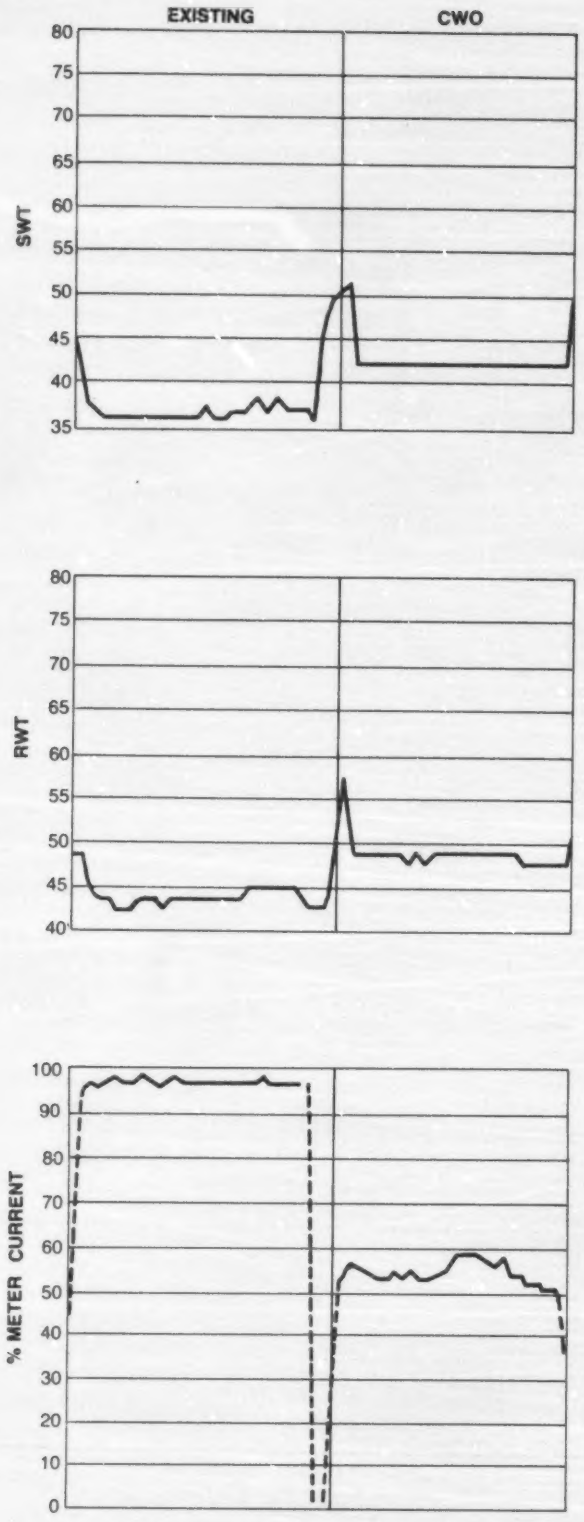

Figure 14 Chiller Optimization Anticipated Results

Tie the Equipment Together

To obtain ultimate optimization and operating efficiency of mechanical equipment, these sections must be consolidated. Improving the operation of HVAC equipment will have a definite effect on the energy budget; however, the solid-state, electric, or pneumatic control system must be interfaced with a microprocessor designed to operate the electrical and mechanical equipment efficiently as a function of external conditions such as temperature, humidity, KWH usage, and KW demand. This microprocessor (Figure 15) must contain various software programs designed to improve building operation and further reduce the operating cost. The software programs must be designed to operate 365 days a year, 24 hours a day automatically, and take into consideration the external variables that affect the operating efficiency of the facility.

A power demand program will efficiently reduce the building's KW demand by 15 percent or more. Power demand systems have been installed throughout the United States for the past one to three years in all types of buildings. Operating data indicates that a physical plant director can realize payback in six months. The power demand controller measures the building's KW usage and controls noncritical loads, defined by the institution, to maintain a maximum KW level. An energy profile of a building, which can be obtained from the local utility, can be used to determine the periods and the amount of KW demand that can be saved using a power demand controller. The peaks that appear on the energy profile can be reduced by deferring certain loads to a later time. Removing the peaks from the building's energy profile will decrease the KW demand and energy cost. The noncritical loads controlled may include domestic hot water systems, exhaust fans, lighting, electric heat, reset of control cycles, and reset of capacity of the centrifugal refrigeration machine. By proper selection of the noncritical loads assigned to the power demand program, a 15 percent reduction or more in KW usage can be accomplished without affecting the operating environment of the facility.

Depending on the building operating characteristics, loads may be required at different times during the day. A microprocessor system is capable of having hundreds of on/off programs that can be assigned to the connected loads. In this manner, the physical plant director can control the on/off time of these loads, keeping the KWH consumption to a minimum. Additionally, once this equipment is started, these loads may be duty cycled to provide even further

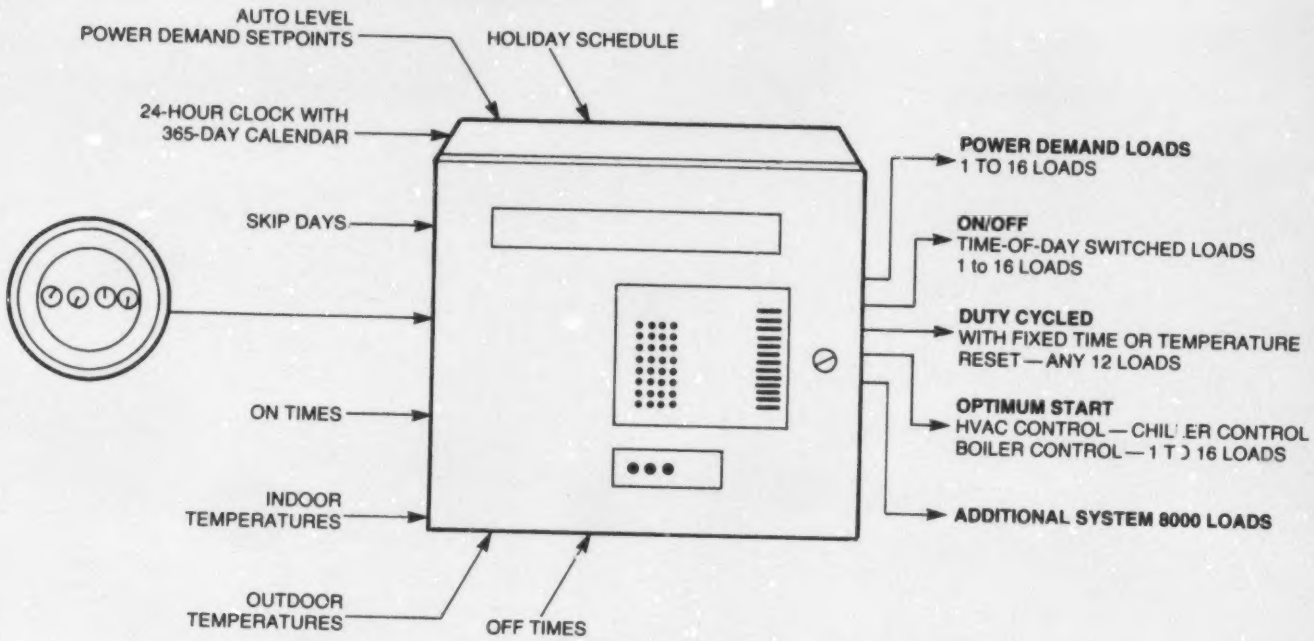

Figure 15 Building Optimization System

savings in KWH consumption. Duty cycling mechanical equipment is achieved by evaluating the facility operation and knowing the equipment's limitations. Many microprocessors have duty cycle programs that are either fixed or can vary the "on" and "off" time as a function of actual building load. In other words, a long "off" period and a short "on" period may be adequate if the space temperature is satisfied. If the space temperature moves away from control point, the "on" period will be increased and the "off" period reduced. As a result of cycling the mechanical equipment, the physical plant director realizes additional savings. These programs alone, depending on installed cost, may provide a system payback in one year.

A good microprocessor system has additional features that will provide added savings to the physical plant director. Due to increasing energy regulations and the need to operate mechanical equipment only when required, these microprocessor control systems will provide optimum start-up of air handling units, boilers, and chillers. This means that an air handling unit can be programmed to start automatically when the space and outside air conditions are at specific levels. Then, based on the building losses (K factor of the building) and internal and external conditions, the actual start time is calculated so the building will warm up or cool down to the precise level at occupied time. The K factor must be adjustable and self-compensating or the physical plant director or operator will spend a tremendous amount of time trying to correct the proper warm-up or cool down cycle to obtain maximum operating efficiency. Prior to occupied time, this start-up should begin with the outside/return air dampers closed. At occupied time, a relay should place these dampers under the control of the standard mixed air control system. Optimum start programs should also be provided for boilers and chillers. Optimum start-up of the boiler and chiller systems are similar to those of the air handling equipment. However, the program should have the start time extending past the occupied time if the space conditions are satisfied. Adding a microprocessor controller with software programs further optimizes the individual systems installed on the HVAC and central plant equipment. This provides a complete system and optimization package for tying the building's electrical and mechanical equipment together into an efficient operation.

The biggest question faced by physical plant directors is what type and size system should be considered. No easy answer is available and the determination of the size of the system must be made only after a detailed evaluation of the facility.

Total Facility Management

Considerable changes in technology and installation techniques have taken place in building automation since the 1940s. The home run panels requiring wiring from each individual device to a central location were replaced first with minicomputers and now with microprocessor systems. A multiple building complex may require full use of the microprocessor as a facilities management system. This facilities management system will interconnect the buildings to a common computer-based console and provide total complex management. This computer-based console contains management programs that guarantee the building will operate effectively 24 hours a day, 7 days a week, consistently. To obtain similar performance from the existing operating personnel is not practical. No person can perform repetitive tasks, error free, with the speed and consistency of a computer. A facilities management system is programmed to monitor the building's operating conditions constantly, to control the consumption and demand of energy, to protect the vital equipment by providing instantaneous alarming of critical conditions, to provide precise centralized control of the facilities environment, and to provide the capability to systematize the building's maintenance program.

Computerized building automation is based on a continuous flow of information between three general areas: the computer-based console (Figure 16), the Field Interface Devices (FIDs), and a wide variety of sensing and controlled devices.

Sensing devices, typically electronic to provide the accuracy required for calculations, feed information to the FID which translates this information into digital language and transmits it to the computer. FIDs are the source of the computer's real-time data (temperatures, on/off status of motors, energy flow). The computer evaluates this data following programmed procedures, and sends appropriate instructions to the FIDs. These instructions are translated and sent out as commands to the controlled devices. This flow of information throughout the facility forms the basis of the facility management system. With the computer's ability to perform calculations, you can have at your fingertips as a management tool, meaningful information such

Figure 16 Facilities Management

as cost per square foot, BTU per square foot, and chiller efficiency.

Much of the system can be defined in terms of its hardware. However, the true capability and actual "power" of the system exist in the software. Software has been developed to deal with two major concerns of facilities management. One set of programs evaluates the physical plant and equipment. The other set is concerned with energy management and consumption. Standard energy management programs include the energy management routines handled by the microprocessor described above as well as complex optimization programs that require sophisticated calculations to be run continuously. Examples of these include: chilled water optimization, supply air reset, custom control actions, enthalpy optimization, and totalization.

There is no such thing as a standard building. Customized "routines" are necessary to deal with a building's unique requirements to obtain the desired facility management. The most effective automation systems allow an operator, without specialized education, to use the English language and follow a step-by-step procedure to create and store in memory multiple command actions and responses. These command actions or series of actions will automatically take place 24 hours a day, seven days a week, in response to selected conditions or events.

The amount of optimization and system complexity depends on many factors such as budget, age of equipment, types of control systems presently installed, size of building or complex, total definition of the building operating schedule, and a commitment to the management of energy through optimization products. Installation of these products plays a major role in controlling the cost of energy, manpower/maintenance, capital equipment operation, and administration. The decision to implement should be made only after a thorough review of present equipment and operation. An energy investment profile will be required to determine the return on investment that could be expected through implementation of more complex microprocessor systems. Single-building or multiple-building complexes with individual meters may use a small stand-alone microprocessor system. Some facilities may install a multiple stand-alone microprocessor system in each building. Or a total facility management system may be designed not only to control energy consumption and reduce operating costs, but also to provide additional management data for use in day-to-day operations. The type of system appropriate for each facility must be determined by the institution's goals, budget, operating procedures, and existing equipment.

Three Categories of Microprocessor-Based Energy Management Systems

Although it is not possible to provide administrators with the exact information needed to determine the best type of system for each facility, this section describes three levels of energy management systems.[4]

Level I Systems. Level I systems generally perform a single function and usually are located close to the equipment being controlled. They are most applicable when the budget is limited, when relatively little time is available for installation, or when the control of individual components is more critical or more cost-effective than comprehensive control strategies.

Typical Level I systems and the functions they perform are as follows:

Time Controls: Time sensitive switching, in its most basic form, starts a function at a given time and ends it at a given time. Many controls are available for almost any kind of time control needed.

Automatic Temperature Set-Back/Set-Up Controls: Automatic temperature set-back and set-up controls combine two thermostats and a timer. One thermostat controls daytime temperature, the other controls nighttime temperature. The timer automatically switches control from one thermostat to the other at present times.

DB Economizer Control: A DB (dry bulb) economizer control senses and compares indoor and outdoor air (OA) temperatures. When cooling is needed, and when OA temperature is sufficiently below indoor temperature — usually by 5°F — the control opens the dampers. When the differential goes below 5°F, dampers are closed.

Enthalpy Controller: Enthalpy refers to the total heat content of air. For enthalpy optimization, the controller continuously monitors and compares the total heat content of the outside air (OA) and return air (RA) streams. The logic panel causes the OA damper to open fully when the RA enthalpy exceeds OA enthalpy. The OA damper closes fully when RA enthalpy is lower than OA enthalpy.

Multizone Control System: A multizone control system matches heating and cooling output to actual demand in a space, relying on outdoor air as much as possible to meet cooling needs. The control

system consists of a central processor, hot and cold deck controls, electronic room thermostats, dampers with associated linkages and motors, economizer controller, enthalpy controller, change-over temperature controller, and a morning warm-up thermostat.

Single Zone Control System: The equipment used for typical single zone HVAC system control includes an electronic space thermostat, discharge air sensor, economizer motors, enthalpy controller, dampers with associated linkages, and a logic panel consisting of three on/off heat and three on/off cool thermostats, an economizer, and an adjustable night setback.

Chiller Energy Management Controller: A chiller energy management controller uses programmed logic to load, unload, start, and stop centrifugal chillers. The controller also resets suction temperature automatically by sensing load requirements; remotely monitors and displays inlet vane position in percentage and chiller operating hours; and starts the standby chiller automatically, when needed.

Level II Systems. Level II systems and devices generally afford remote control and perform more than one function. They are typified by the latest generation of microprocessor-based demand control devices which also perform duty-cycling and optimized start/stop. They are most applicable when functions to be performed are limited and the number of points to be monitored and controlled is usually less than 100.

Demand Controller: A demand controller prevents electrical demand from exceeding a predetermined maximum. Certain interruptible or secondary loads are connected to it. As demand approaches maximum during an interval, secondary loads are shed. When demand subsides, or when the demand interval ends, the secondary loads are restored.

Multiload System Programmer: A multiload system programmer is used for automatic scheduling of various electric heating and cooling units and other electrical loads in a building. Typically, the programmer package includes an integrated circuit logic panel and two remote sensors, one for outside temperature and the other for indoor temperature at night. Both sensors are connected to the logic panel by low-voltage wiring.

The programmer operates by switching a limited number of load or load group contacts between "on" and "off" according to a corresponding number of independent seven-day programs stored in the logic panel memory. Battery packs may be used as protection against power failure.

Multifunction Programmable Controller: Multifunction controllers perform demand control, time-of-day load scheduling, optimized start/stop, and duty cycling.

Duty cycling consists of shutting down a system for predetermined short periods of time during normal operating hours. Its use is based on the theory that HVAC systems seldom operate at peak output.

Level III Systems. A Level III system is a central building control system that uses a microcomputer or minicomputer to monitor and control various points. Man-machine interface usually occurs in a central operations area which contains various consoles. In some cases the computer and support devices are remote with data generated in the building being transmitted to the computer via leased telephone lines.

Level III systems usually are appropriate when: the facility comprises many buildings or a single high-rise with a central plant and several remote mechanical equipment rooms; 200 or more points must be controlled; numerous optimization functions are called for; and control decisions must be based on a number of parameters and conditions as well as the series of events occurring.

Functions performed by Level III systems can be segregated into three categories: basic functions, which are generally applicable to a broad range of systems and equipment; optimizing functions, which improve the operating efficiency of a given piece of equipment or system by monitoring performance and performing adjustments on a real-time basis; and operational functions, which are associated with systems monitoring and alarm.

Basic Functions

Demand control, duty cycling, and programmed start/stop are three of the most important basic functions. Some of others are:

Outside Air Temperature Cut-Off: Outside air temperature cut-off is applicable for most, but not all, space heating systems. An outdoor temperature-sensing control cuts off the heating system when the outdoor temperature rises to within 5°F of the indoor design temperature, or to a minimum of 40°F.

Warm-Up Night Cycle: A warm-up/night cycle controls OA to minimize the introduction of outside air

when it will create a thermal load and the area is unoccupied. This function applies during warm-up or cool-down cycles prior to occupancy.

Night Set-back: Night set-back is programmed under Level III much as it is in Level I, except control signals come from the central equipment rather than local thermostats.

Optimizing Functions

Optimizing functions are those that improve the operating efficiency of a given piece of equipment or system by monitoring performance and performing adjustments on a real time basis. Typical optimizing functions include, but are not limited to:

Economizer Cycle: Both db and enthalpy economizer cycle can be used. If periods of high humidity seldom occur in the area, the additional expense of an enthalpy economizer will not be cost-justified.

Hot/Cold Deck Temperature Reset: Hot and cold deck temperature reset is applied to simultaneous heating/cooling systems to regulate their supply temperatures in accord with actual needs rather than potential needs in the event of severe outdoor conditions.

Discharge Air Temperature Reset: Discharge air temperature reset is similar to hot/cold deck temperature reset. It adjusts the cooling discharge temperature upward until the zone with the greatest demand for cooling has closed its reheat coil valve. Return air humidity may be monitored for high limit.

Chilled Water Reset: Energy required to chill water in reciprocating or centrifugal electric refrigeration machines depends on several parameters, the most significant being the temperature of the chilled water leaving the machine. Refrigerant suction temperature and leaving water temperature are interdependent. Unless strict humidity control is necessary, most chilled water temperatures can be elevated during operating hours, energy being saved by resetting temperature, allowing it to rise to satisfy the greatest cooling requirements.

Outside Air Schedule Reset: Many hot water systems permit reduction of supply temperature when outdoor temperatures rise. The OA schedule reset function resets the hot water supply temperature controller as outdoor temperatures rise or fall.

Start/Stop Optimization: HVAC components sense thermal inertia of the building and outside weather conditions, plus the capability of the system to increase/reduce temperatures during start-up and shut-down times. These capabilities allow the HVAC system to operate the minimum amount of time needed to meet building requirements.

Air Distribution Optimization: Air distribution optimization involves controlling dampers by a stop/start program to stop the flow of conditioned air to areas that do not need it. Supply and exhaust fan dampers are positioned by static pressure sensors.

Chiller Plant Optimization: Loading control optimizes performance of chiller installations by resetting supply and return water temperature according to the needs of each chiller unit. Sensors monitor differential temperatures at evaporation, condenser, and reclaim sections. Flow is measured at these sections and a computer makes the calculations needed to determine the most efficient combination of chillers to be operated.

Boiler Plant Optimization: Boiler plant operation is optimized either by using electronic probes to measure oxygen passing through the stack(s), then regulating the air flow for maximum combustion efficiency, or by mixing boiler water with cooler outside water to lower temperature, thus reducing fuel flow as the boiler load decreases. Automatic flue dampers close when burners are off to prevent loss of heat.

Operational Functions

Operational functions are primarily those associated with monitoring and alarm.

Chiller Profile Generation: A chiller profile is a printed record of chiller equipment operating status and includes such data as demand in kw, return and supply water temperatures, etc. Analysis of this data identifies efficiency and cost factors.

Boiler Profile Generation: Recorded operating data is collected in "profiles," from which curves are plotted to determine operating efficiency. These curves become the basis for developing optimization routines.

Looking Ahead

Although energy costs and utility rates no longer can be projected for the next three to five years, the price of energy is increasing at a tremendous rate (Figure 17). The consumer's demand is increasing also, and some parts of the country have experienced shortages and curtailment of gas, oil, and electricity. As the heating and cooling seasons approach in the

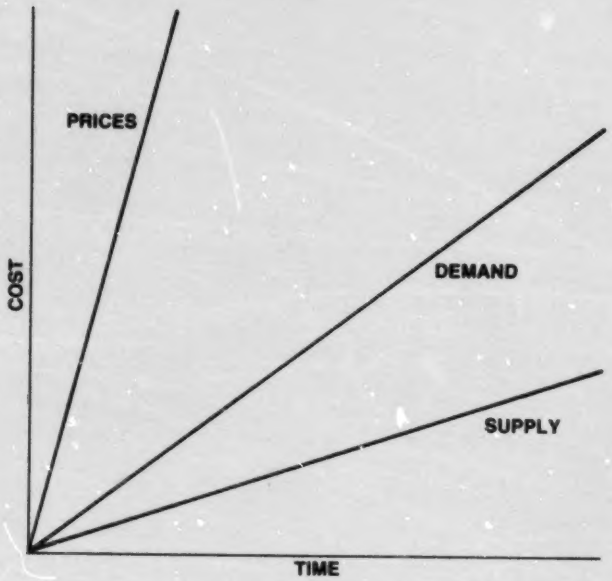

Figure 17 Price vs. Demand vs. Supply

future, we may experience this to a greater degree. We know the supply is somewhat questionable. The amount of oil and gas that will be imported to the United States has been limited by the federal government and so it, too, has to be added to the list of future "unknowns." For a physical plant director, the energy crisis is a tremendous problem. For those who administer or prepare budgets, it becomes even more difficult. For those who sit on boards of education or boards of trustees and work with educational budgets, it gives a feeling of uncertainty when future operating costs must be discussed. Additional money is required to cover the increasing operating cost. In a given fiscal year, the actual cost may increase 15 to 40 percent above the projected budget. In an educational budget, the largest single account is the education fund, and the account with the most unknowns is the operations/building/ maintenance fund. As much as 70 to 80 percent of the total budget is aimed at the educational process, leaving a percentage of the remainder to the building fund. This money is required for retrofit, utility payment, and snow removal, and it usually means a shortage in the end.

Solar control systems (Figure 18), are being field-tested, and many installations have been successful. Typically, solid-state control systems are used to measure solar collector temperatures and to operate pumps that change the flow of water from the collector to the storage tank to the air handling ur' etc. These have been very successful; however, the cost of the installation and equipment is too high for many at the present time. Improved technology in solid-state control systems and improved manufacturing techniques for solar collectors will cause even greater use of solar energy.

Solid-state technology will continue to improve, and electronic control systems will be installed with greater frequency. Microprocessors presently used for several years in building automation systems and power demand systems will be designed for HVAC control. The use of microprocessors as a complex package or as individual components will increase as the cost of this technology decreases. Improvements in the manufacture of the individual microprocessor chips are providing inexpensive A to D convertors and reducing the need for multiple power supplies. The improvement has made this technology more attractive to the control industry. In the 1980s, microprocessors will be used for individual air handling unit control systems.

The 1980s will also bring wireless control systems. Wireless control systems employing microprocessor technology enable manufacturers to provide a fail-safe, reliable coding and transmission approach between the controlled devices and the central microprocessor system. Also, power line carrier

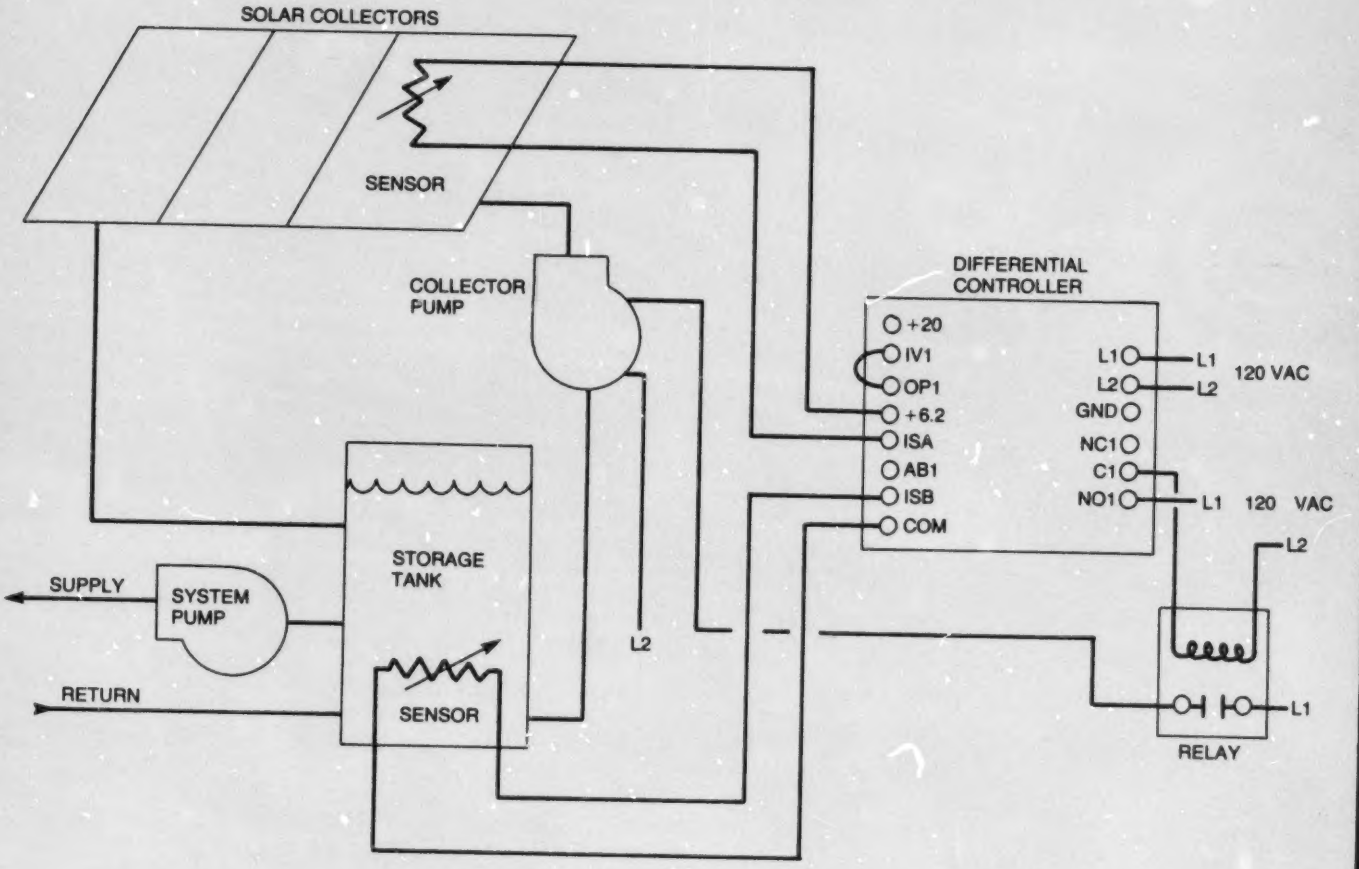

Figure 18 Solar Heating Systems

systems are presently being installed for power management applications and will become more refined during the 1980s, offering a reduced installation approach in existing buildings.

Owner's Role

The owner's role is one of calibration and maintenance to meet energy regulation guidelines. The immediate answer is calibration and planned maintenance of the existing HVAC systems. We must then consider retrofit which will upgrade the performance of the air handling units, boilers, chillers, building optimization and perhaps even complete facility management. The only way to maintain the building fund budget and operate within its restrictions is to reduce the rapidly increasing utility costs. Funds resulting from the operating cost reduction can then be used for system retrofit. In the 1980s the calibration, maintenance, and retrofit phase must be surpassed. We will have to look hard at the mechanical equipment that is operating within the facility and give strong consideration to replacing these outdated systems with new variable air volume systems, heat pumps, and solar systems.

Manufacturer/Vendor's Role

The manufacturer/vendor has a very important role of providing products and services to the institution. These products and services must reduce operating

costs as well as comply with DOE regulations. This service must be provided in the form of planned maintenance and system calibration. The vendor must provide energy management products for use on a retrofit basis to optimize operation of the air handling equipment, chillers, boilers, and the building itself. The vendor must also invest in the development of higher technology control systems.

As we move into the 1980s, the next generation of control products will be developed. Although development will involve enormous expense, these products must improve operating efficiency and reduce installation costs. To the building owner, the manufacturer, and the contractor, the answer is *cost avoidance* through improved control systems using the latest state-of-the-art microprocessor technology.

CHAPTER FIVE

SOURCES AND COSTS

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More than 100 suppliers sell microprocessor-based energy management systems. These suppliers are listed in Appendix A of this publication. No two suppliers offer identical energy management systems. And many of the manufacturers are very guarded about revealing detailed or exact cost information.[5] They generally prefer to give rough budget estimates based on the total number of points in a system. For these reasons, it is difficult to project actual costs for an energy management system.

The purpose of this chapter is to provide estimated costs for hardware, software, staff support, and maintenance contracts.

The five main cost components of an energy management system are:

1. General costs
2. Central control center cost
3. Transmission center cost
4. Facility connection cost
5. Sensor/actuator cost.

General Costs

The general costs of the system include:

a. Estimation
b. System engineering
c. Shop drawing preparation
d. System testing and debugging
e. Training
f. Maintenance Contract.

All of the general costs involve a considerable amount of overhead time, thus making them only slightly dependent on the number of facilities and sensor/actuators connected to the system.

Central Control Center

The central control center consists of the following main components:

1. Central processing unit hardware
2. Peripheral hardware and associated software drivers
3. Operating system software
4. Command software
5. Application software
6. Communications hardware
7. Communications software.

The cost of these components is relatively constant, regardless of the number of facilities or sensor/actuators that are connected to the system.

The Central Processing Unit Hardware

The central station controls hardware typically represents from about 10 to 20 percent of the total investment. A wise investment in the "heart" of the system establishes the real capability of the complete system. Try not to buy short on this end of the system. The central processing unit should be at least a 16-bit processor and should be selected with built-in capacity and features for the entire project, including a 20 percent cushion for future expansion. If funding is tight, then the initial purchase could be a first increment of a modular, expandable chassis. Certain manufacturers have three series of central station equipment; beware of the bottom-of-the-line equipment.

The equipment selected should be of a well-known manufacturer to ensure future procurement of parts, programs, and service.

A reasonable central control station starter set should include a microcomputer (or minicomputer) with 32K memory expandable to 128K, and a disk auxiliary storage system, a CRT with key pad, a console printer, a remote alarm printer, and a communication multiplexer. The CRT key pad should have function keys for common addresses such as start, stop, alarm acknowledge, alarm summary, reset, increase, decrease, and execute. A back-up power supply should, of course, be included with any starter set. The loss of the computer due to loss of power on a computer malfunction usually cannot be tolerated. Figure 19 illustrates the costs of various control system components.

Peripheral Hardware Priorities

The consequences of a computer malfunction can be avoided by providing a back-up computer, either a copy of the main or some less expensive version with reduced capabilities. This back-up capability should be a first choice in the selection of optional equipment.

Additional printers are an early choice for add-on purchases. Printers dedicated to fire alarm, maintenance, load shed security station, and night-time duty office should be considered.

Operating System Software

System software comprises the basic programs that cause the computer to function. It includes operating procedures for input/output devices and programs that load and unload command and applications software.

Command Software

Command software refers to that group of programs that permit the operator to communicate with the energy management system to perform required actions, such as monitor a control point or send an instruction.

A good command language will provide the interface in easy-to-use English commands which make such details as building communication transparent to the operator. Most modern systems use a CRT or television-like terminal for entry of commands and display of data and status. One convenient method uses a "menu" approach in which a primary menu of functions available is displayed along with instructions for operator interaction. The command language is a critical part of the software supplied by any vendor since it is the only interface between the system and physical plant operating personnel. If the

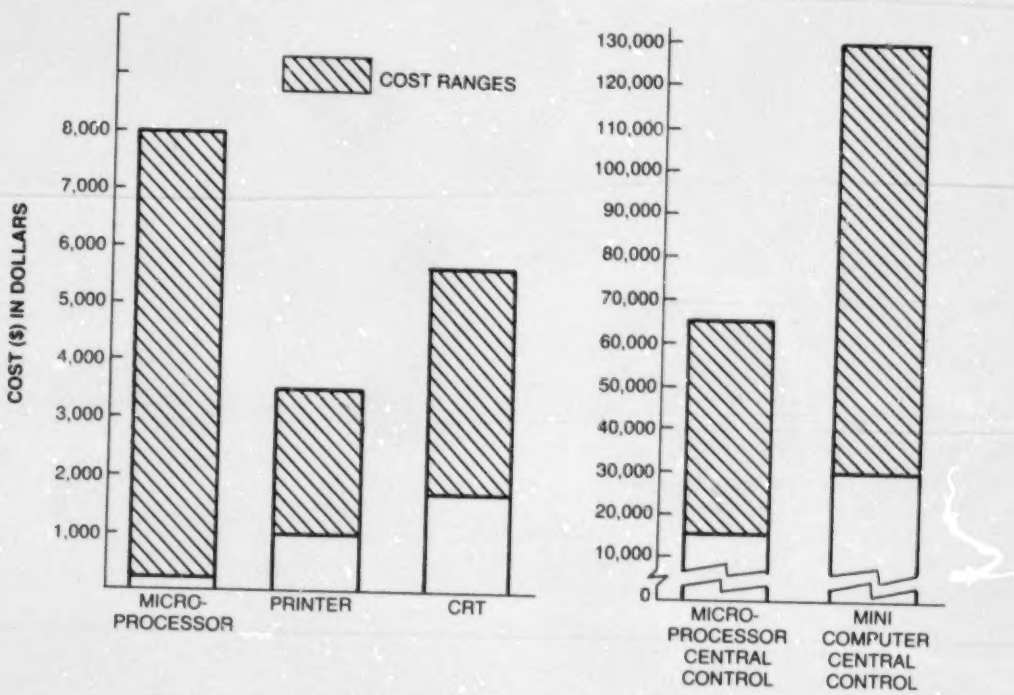

Figure 19 Cost Ranges of Various Control System Components

command language is difficult to use, special operators might have to be employed for three shifts, thereby increasing the overall operating costs of the system.

Applications Software

Control system vendors have developed and tested software for their system. Software varies from vendor to vendor but will usually include the following:

- Power Control and Monitoring
- On/Off Control
- Monitoring
- Start/Stop Optimization
- Outdoor Comfort Factor
- Damper Operation
- Data Gathering
- Chiller Performance
- Indoor Temperature Humidity Control
- Boiler Efficiency
- Chiller Output and Chiller Efficiency
- Hot Water Generator
- Boiler House Output
- Water Treatment
- Motor Generator Exerciser
- Security
- Fire
- Communication with other Computers
- Pressure Differential

Custom software is written for a particular purchaser; therefore, the owner must describe in detail the function to be controlled and how it relates to the system.

Figures 20 and 21 illustrate cost ranges for controlling various individual building functions.

Table 3 shows the software costs from a survey of suppliers with systems operating on various campuses.

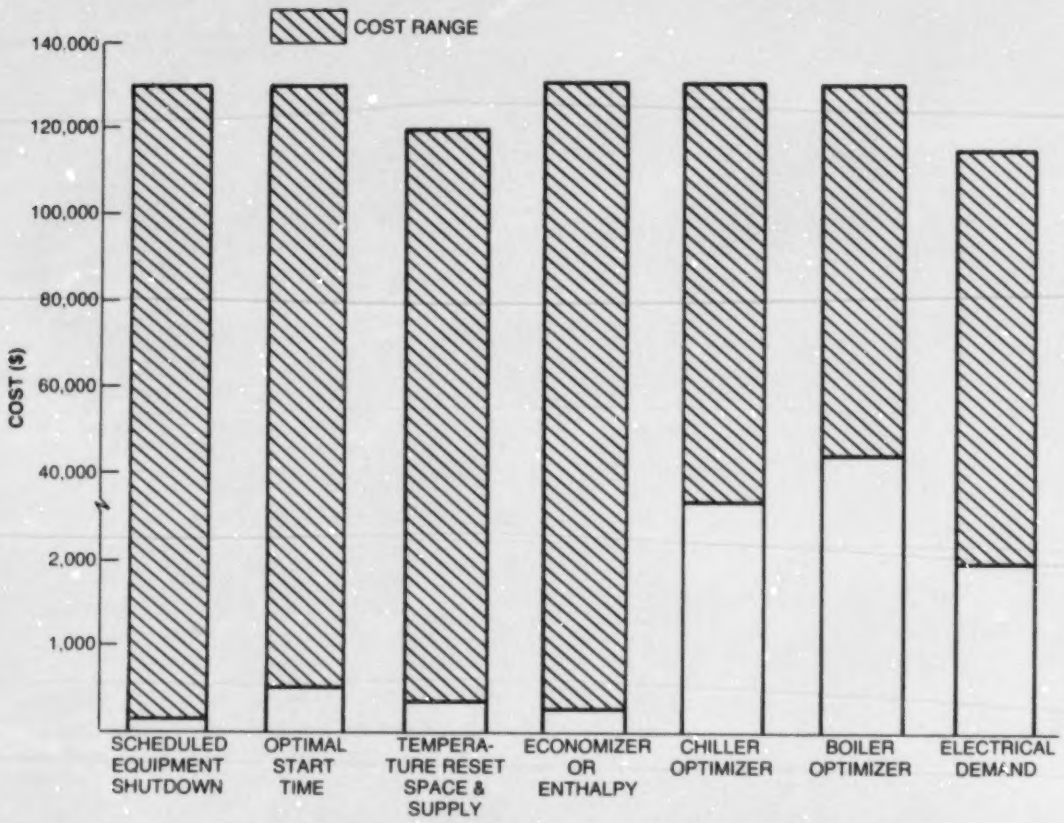

Figure 20 Cost Ranges for Controlling Various Individual Building Functions

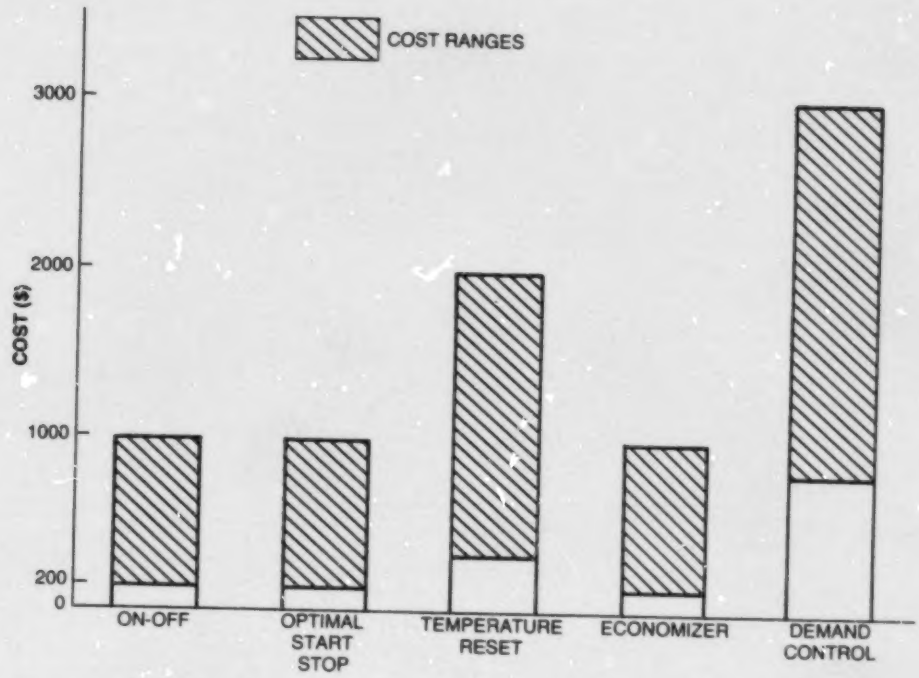

Figure 21 Cost Ranges for Adding Control Functions to a Building Microprocessor

Table 3 Examples of Software Cost

Function	Supplier 1	Supplier 2	Supplier 3	Supplier 4
Load Management	$2,000	$2,900	$5,000	$2,500
Optimum Start/Stop	3,000	2,900	5,000	7,000
Temperature Reset	6,000	2,900	5,000	
Chiller Optimization	6,600			
Outdoor Air Control	1,500			
Guard Tour	2,000			
Enthalpy	5,000	2,900		

Power Management and Basic Monitoring $2,700/month.

Communications Hardware and Software

The central station controls should include a communications multiplexer with sufficient RS232 channels to accommodate all building microprocessors. Since the building processors will normally be connected in a series-parallel arrangement or on current loops, the number of communication channels is usually much less than the number of buildings.

The communication program software is intimately tied to the reliable operation of the total system. These programs need to use a standard protocol such as ASCII synchronous or another well-defined standard technique. The programs should include error detection and possibly automatic error correction. At the very least, they should include the common cyclic redundancy check which ensures the correct reception of the number of bits transmitted on the line. Communication failures should be logged on the printer with an alarm for the operator.

Transmission Center Cost

The cost of the overhead transmission cable, underground transmission cable, and telephone modems is basically a function of the number and location of facilities connected to the energy management system. From a hardware standpoint, communication between the microprocessor and central control computer is relatively simple and inexpensive at data rates up to 1200 baud. Higher communication rates are available at higher cost per processor and significantly higher cost for communication cables. Either direct point-to-point wiring can be installed by the user or lines can be leased from the telephone company.

Facility Connection Cost

Facility connection costs are those fixed costs associated with connecting a facility to the energy management system that are independent of the number of sensors/actuators that are installed within that facility.

The sensor/actuator cost is the cost to add a sensor/actuator to the system, assuming a FID that the point will be connected to is already available in the building. Cost components associated with each sensor/actuator are:

1. A single conditioning device usually in the form of an integrated circuit card that plugs into an appropriate slot in the FID
2. Wiring from the FID to the sensor/actuator
3. The sensor/actuator itself
4. The installation and interface of the sensor/actuator with the existing local control system
5. Local controls that must be replaced, repaired, or added
6. Miscellaneous new equipment (dampers, ductwork, thermometer wells, etc.)
7. Definition and entry of each sensor/controller into the central control center data base.

Maintenance Contract

When deciding whether to use an in-house maintenance or an outside source, you should consider several considerations. Much depends on the size of the operation. If a large in-house maintenance staff already exists, appropriate personnel may be able to take care of electronic gear. Recognize, however, that spare parts must be stocked, space to stock those parts must be allocated, and personnel to keep inventory current must be assigned. Large facilities may not consider this an additional burden, but smaller ones may not wish to be bothered with additional people, parts, etc. For smaller facilities, therefore, a maintenance contract with an outside service organization may be the answer.

If an outside maintenance organization is to be used, competitive bids should be solicited. All documentation mentioned in the specifications must be available to the bidders. If the specifications do not require wiring diagrams of the system to be delivered, the only feasible maintenance organization is the supplier of the equipment.

Once the decision has been made, it is beneficial to have the maintenance staff actively engaged in the installation and commissioning procedure. They can participate with the operators in the initial training provided by the contractor.

Note that the complete system requires maintenance, including the computer, peripheral equipment, data links, local sensors and controllers, trunk wiring, etc.

Additional Operating Costs

Operations and maintenance cost for the energy management system deserves special note. In addition to the maintenance contract cost, an operator must be employed to properly use the system. Traditionally, a total annual operation and maintenance cost of 10 percent of the original system cost is included in the budget.

CHAPTER SIX

PURCHASING PROCEDURES

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Purchasing a microprocessor-based energy management system is a complex procedure. This chapter outlines various purchase methods and describes the major elements that should be included in contract documents. The key to a successful energy management system is good definitions. This applies both to purchasing procedures and to contract documents. The majority of problems during the construction phase of the project can be traced to incomplete definitions in one of the contract documents. The better the initial definition, the fewer and less complex the questions will be.

There are several methods of purchasing systems. Obviously, the method depends on a number of factors and may be greatly influenced by the legal requirements of a particular institution.

Negotiated Sale

First there is the *negotiated sale*. In the past, this was practically the only way to obtain certain features or functions because they were generally offered by only one vendor. With the passage of time, all vendors added capability. Many requirements can be met by more than one vendor. It is usually relatively simple for the vendor to make small changes at little if any additional cost. This is possible because the vendor usually has higher profit margins on negotiated sales than on competitively bid projects, especially if he knows he has no competition when he quotes his final price. With this method of procurement, the buyer receives less benefit for the money.

Plan and Spec Procedure

The *plan and spec procedure* introduces some competitiveness to the pricing process. However, since the specification is usually structured around a particular vendor's hardware and software, the vendor will usually try to get as many unique proprietary hardware and software definitions in the spec as possible. By doing this, he reduces the ability of other vendors to compete. This approach can lead to satisfactory results if the vendor offers exactly what is required but the buyer probably will pay more for the system than he would if the bidding were more competitive.

Flat Spec Method

The *flat spec method* of purchasing is most often used for the expansion of an existing system. However, it is occasionally used for the procurement of a new system. This approach results in getting the exact vendor specified but at a price generally far above what it would have been in the open market.

These first three approaches all lend themselves to "bricks and mortar" purchases rather than to automated systems purchases. In addition, they all violate one of the cardinal rules of system purchasing — don't fall in love with a vendor.

Two-Part Procurement

The next two types of procurement include a technical proposal. The first of these is known as *two-part procurement*. Vendors submit a technical proposal in response to a set of bid documents that include the performance specifications for an institution's facility control system. The technical proposal is the vendor's detailed explanation of how he plans to satisfy the institution's needs. It covers all the hardware, software, and performance capabilities. These proposals are submitted without prices. The proposals are evaluated by the buyer's technical review team, and the vendors that are compliant with the system specifications are asked to

submit pricing. After review of pricing, a contract is awarded. One major advantage of this approach is that the owner can evaluate all the vendors and their qualifications prior to the pricing proposals. This reduces the amount of evaluation necessary after prices are received and increases the objectivity of the technical evaluations. The main disadvantage of this approach is its impact on the vendor. Two-part procurement requires him to make two concerted efforts on the bid. And if the time between the technical proposal and the pricing is too long, it may be difficult for the vendor to assemble the people who prepared the technical proposal to do the pricing for it. However, from the owner's point of view, this is a good approach to procurement. When it is done with complete bid documents that include thorough project definition, it can achieve good results.

Request for Proposal

In the second of these approaches, known as Request For Proposal (RFP), the technical proposal and the pricing are submitted at the same time. If it is legal in the buyer's jurisdiction, he should require the vendors to submit the technical proposal and the price quote in separate sealed packets. At the bid opening, both packets are opened and stamped "received" but they are not read. The technical proposals are delivered to the technical review team and the price quotes to the financial review team. The two teams are not allowed to exchange any information until they have completed their evaluations.

In this case, as in the two-part procurement, the technical team ranks all vendors in accordance with compliance and capabilities. At this point, the bids of all but the two or three highest-ranked vendors should be eliminated from further consideration.

By now the financial team should have reviewed the price quotes for completeness, compliance, and correctness, and ranked the quotes in ascending order. This list should be made available to the technical team only *after* they have narrowed the field to two or three vendors. At this time, an evaluation of price performance can be made and a contract awarded.

If possible, the highest ranking vendors should be interviewed so that any questions about approach can be answered. For example, if the technical proposal includes modems but it's not clear whether they are included in the purchase price, the vendor should be asked to clarify this point. After these discussions, if it is legal in the buyer's jurisdiction, he should ask each vendor to prepare a "best and final" offer. After these offers are submitted, a contract can be awarded to the most cost effective vendor. The unsuccessful bidders should be told only that they were not successful; they should not be told their ranking.

This approach has the greatest potential for buying the most system for the least dollars.

Contracts

Whatever the bid procedures used, at least two contracts are usually involved—one with a consultant and one with the successful bidder. The consulting team is very important. It should include an engineer who specializes in HVAC control design, a systems analyst who specializes in mini- and microcomputer system hardware and software design, and, if relevant, an instrument engineer and fire and security specialists. Competency in these required areas is a must for the consulting team.

Before the buyer and the consultant can arrive at an agreement, it is essential that both understand what is entailed in the project. The areas covered in the consultant's contract should include:

1. The Project
2. Definitions
3. Consultant's Services
4. Extra Consultant Services
5. Future Consultant Services
6. Owner Responsibilities
7. Construction Cost
8. Compensation
9. Termination of Agreement
10. Ownership of Documents.

Project

This portion of the contract should name the project and describe the services to be provided by the consultant. It should also include budget information. The owner determines the project budget which includes all costs for design, construction, and related management. This is not usually assigned a dollar value in the contract. The construction cost limitation, which is assigned a fixed dollar amount, is the owner's maximum construction cost, not including the construction contingency.

Definitions

This section should define any terms used in the contract, such as agreement, project budget, construction cost limitation, procurement documents, contract documents, design, owners design review, construction, and direct personnel expense, among others. The definitions should be specific.

Consultant's Services

This section must include a detailed description of the work to be provided by the consultant. The first item is usually the scope of work, a general definition of the tasks to be performed and sequence of performance. In addition, this section should include the major features to be incorporated in the design. At a minimum, these features should be as follows:

1. The owner will be able to fully maintain and operate this system without limitation or restriction.
2. The owner shall have access to the full and complete software programs, including all manuals, instructions, and complete annotated source code listing for all application programs.
3. The software shall be designed so that the owner, at his discretion and without vendor support, may delete any existing point, add any new point, or redefine any point in the system.
4. The computer and peripherals supplied for this system will be standard catalog products of a company engaged primarily in the manufacture of mini- and microcomputers and shall not be modified by the system vendor in any way. The operating system software shall be a standard product of the computer manufacturer and shall not be modified in any manner.
5. Both the computer and the operating system software must be fully supported by and eligible for maintenance from the computer manufacturer. At a minimum all components shall have at least two sources of supply and shall meet industry standards (i.e., electronics components second sourced, field temperature sensors industry standard 100 or 1000 ohms at 32 degrees F., three wire RTD (resistance temperature device).
6. The consultant's design will provide non-proprietary software based on computer equipment that can be competitively bid.

The first task defined for the consultant is usually preparation of a document called the feasibility study. This task typically includes an in-depth study of several feasible methods of providing the owner with a facility control system. The consultant should select the method he considers optimum, justify his selection, and discuss the methods not selected and the reasons they weren't selected. The optimum method should be described in sufficient detail for the owner to make an in-depth technical evaluation of that method. The feasibility study should also include a budget estimate of the labor and material required to build and install the selected system. In addition, a tentative project timetable should be developed by the consultant and included in the feasibility study. The amount of time allocated for this study may vary depending on specific considerations but in most cases, it should be completed in eight weeks. The owner then reviews the study and provides written comments if necessary. Written notice of acceptance of the feasibility study should include authorization to proceed to the second task, the preparation of *Bid Documents*. The bid documents include the standard documents furnished by the owner (Boiler Plate), the final working drawings, the technical specifications and the 1/0 summary that set forth in detail all the requirements for construction. While a thorough job on the bid documents will not be quick or cheap, the thoroughness and completeness of these documents will be reflected in the vendor pricing. The fewer assumptions and worst case estimates the vendor has to include in his pricing, the tighter he can figure the job. This thoroughness will also result in fewer unpleasant surprises for the owner and the vendor as the job progresses.

Areas that should be addressed in the bid documents will vary from project to project. However, certain items should be included in almost all bid documents involving the procurement of facility control systems. The proposal form is one. The proposal form should include lump sum bids for the base bid and any alternates. Alternates should be specified in descending order of importance or consideration. These bids should be based on unit prices furnished as a portion of the proposal package. This pricing structure should conform to the project budget the consultant furnished in the feasibility study and bid documents. This will facilitate comparisons of vendor pricing. Unit pricing should also be included on components to facilitate additions and deletions. As a further protection for the owner, the proposal form should include a future pricing guarantee, stating that the unit prices itemized in the proposal will be offered to the owner at the proposal price plus a cost adjustment figure not to exceed the Consumer Price Index. This will

tend to discourage "low ball" bids and "rip off" additions. The proposal form should also cover service rates and rates for service above and beyond warranty. These rates should be good for at least one year and preferably two years beyond system acceptance. Items to be covered should include:

Field Labor	$____ per hour for work time on site
Shop Labor	$____ per hour for work at the repair facility of the vendor
Replacement Components	Cost of components plus ____ percent overhead and profit
Outside Service	Cost plus 5 percent overhead
Replacement Equipment	Not to exceed proposal unit prices
Application Engineer	$____ per hour
Design Engineer-Hardware	$____ per hour
Design Engineer-Software	$____ per hour.

All these prices should be predicted on service during normal business hours with increases specified for overtime.

Vendors should also be required to supply quotes for separate annual maintenance contracts for both hardware and software. Pricing should be structured to reflect the warranty period on both these items. For example, with a one-year warranty, pricing might be as follows:

Software Maintenance:	Vendor to include scope of services including response times
First Year Rate	$_____ per month
Rate for Second Through Fifth Year	$_____ per month

In addition to specific performance requirements to be delineated in the specs, a statement of performance level during the guarantee period should be included. For example:

Guarantee

a. *Guarantee Period.* The contractor shall provide guarantees as defined hereunder for a period of one year after final acceptance by the owner.

b. *Guarantee Requirement for Digital Data Acquisition and Control System*

(1) System shall perform all data acquisition, control, and reporting functions as shown and specified.

(2) The availability of the digital control system, including operation under conditions of digital equipment failover, initiated either automatically or manually, shall be not less than 98.0 percent for any consecutive period of six months.

(3) The availability will be calculated by the following:

$$\frac{\text{(time since beginning period)} - \text{(downtime during period)}}{\text{(time since beginning of period)}}$$

(4) Downtime will commence after a system, subsystem, or device failure at the time of initial attempt by owner to contact contractor's serviceman and will cease when effective device, subsystem, or system becomes operational.

Owner will maintain record of system or device availability. When contractor's serviceman responds to the call, he shall initial the record acknowledging the time of the initial attempt by owner to contact him. He will also initial the record of time of failure correction. The absence of the initials of the contractor's serviceman will be his agreement with the recorded times.

(5) For purposes of determining availability figures, the following guidelines will apply:

(a) Downtime of system component that is automatically backed up upon failure shall not be considered system failure provided that downtime of failed component does not exceed 24 hours.

(b) Downtime of a portion of an I/O subsystem affecting 16 or fewer inputs or outputs shall not be considered system failure provided that remaining portion of the system functions as specified and downtime of failed portion does not exceed 24 hours. Downtime of a portion of the system affecting more than 16 inputs or outputs is a system failure.

(c) Downtime of the following peripherals shall not be considered system failure provided remaining portion of the system functions as specified and failed device is repaired within seven days:

(1) One output printer failure. Two printers failing simultaneously shall be considered a system failure.

(2) One operator's console failure of two or more operator's consoles. Two or more operators' consoles failing concurrently shall be considered a system failure.

(3) Magnetic tape drive and controller.

(d) Total shutdown of computer system resulting from hardware or software fault shall be considered system failure.

(e) Erroneous and irrational computer command to the process that can be specifically related to computer system shall be considered system failure.

(f) Failure of the system to provide specified response shall be considered system failure.

(g) Failure of a disk drive or controller shall be considered a system failure unless a spare unit is purchased.

c. *Guarantee Requirements for Sensors and Transmitters.* Each device shall perform its intended function within the specified operating accuracy and repeatability. The availability of each device shall be not less than 98.0 percent for any consecutive period of six months.

d. *Obligation*

(1) Owner will make first attempt to diagnose and correct system or device faults. If unsuccessful, owner will attempt to contact contractor's servicemen.

(2) Provide diagnostic work connected with faults or failure of the subsystems and systems.

(3) Utilize technical service personnel designated and factory trained by manufacturer. Perform services within one calendar day after notification by owner.

(4) Any device, system, or subsystem that fails to meet contract requirements or published performance specifications of the manufacturer during one year period after final acceptance by owner must be repaired or replaced as directed by the owner's representative at no cost to owner.

(5) Penalty. At the end of each month, if availability of system becomes less than 98.0 percent for any consecutive period of six months, a penalty equal to 10 percent of monthly maintenance charge for every percentage point the system's availability is below 98.0 percent will be debited from succeeding maintenance bills. This provision shall become part of the maintenance contract and shall continue after the end of the guarantee period.

Other areas that should receive special attention and thorough review involve the "Point List" and selection and placement of sensors. The "Point List" should include the name of every field point to be integrated into the system along with a definition of the point. This definition should include: Range: i.e., 40-95° F., On/Off, Start/Stop; Location: Sensor specification; Mounting information: Power requirements with blanks left for Manufacturer: Model Numbers and Field Interface Device Number. Completion of the blanks by vendor will result in a complete set of field documentation. Definition by the consultant's instrument engineer in conjunction with the HVAC control engineer will result in optimum system performance of the facility control system. If this is not done, the owner may have to take whatever the vendor elects to supply, at a cost to system effectiveness and accuracy.

The third task is *Bid and Award Assistance.* The consultant assists the owner in solicitation of bids. This includes preparation and issuance of addenda and clarification documents, including drawings. He should interpret the Final Plans and Specifications. (A word of caution here: any interpretation should be made in writing and copies sent to *all* plan holders and the owner. Failure to do so may result in problems during construction. This will also always cost more to remedy than if all bidders had been advised prior to bid date. If possible, the consultant's contract should include this particular instruction with a provision that the owner can recover from the consultant any additional costs.)

The consultant should attend the pre-bid conference which should be held halfway through the bid period. Attendance at the pre-bid conference should be specified in the Bid Documents as mandatory for the bidders. The pre-bid conference should be held at the job site and should include a walk-through inspection of all the areas affected by the facility control system project.

The consultant should also attend the bid opening, after which he receives the technical proposals for review and evaluation. If the consultant is also responsible for reviewing the price quotes, he should not see them until the technical review is complete and evaluations have been given to the owner. This prevents price from influencing the technical

evaluation. If oral interviews are held as a part of the evaluation, the consultant should participate.

And finally, after comparison of price quotes with performance evaluation, the consultant recommends the most cost effective bidder. The owner then notifies the successful vendor.

Task four involves *Construction Support*. The consultant should supervise the construction of the facility control project to make sure the vendor is completing the project in conformity with the contract documents and the design intent. The consultant's contract should specify a minimum number of visits to the job site. This provision protects both the owner and consultant and is particularly important if the consultant's office is not in the same city as the project. The consultant should be required to notify both the vendor and the owner of any non-compliance with the contract documents on the part of the vendor.

The consultant should be responsible for review of the vendor's periodic estimates for partial payment. The consultant should issue written certificates for payment to the owner. These certificates indicate that the work has progressed to a specified value and, to the best of the consultant's knowledge, is in compliance with the bid documents.

The consultant should review and approve work schedules, shop drawings, equipment submittals, prefabrication submittals, manuals and software documentation. Also during the construction phase, the consultant should make any interpretation of the contract documents requested by the vendor. These interpretations should be done in writing with copies to the owner, and they should be timely so they do not impede progress on the project. The consultant should prepare any change to the construction documents that becomes necessary as a result of interpretations requested by the vendor. For each contract change, the consultant should analyze the price and time proposals received from the vendor and advise the owner whether the proposal is acceptable.

One of the last things the consultant does as part of Construction Support is to participate in the final inspection and acceptance test of the complete facility control system. The levels of performance required should be explicitly detailed in the bid documents. The exact scenario for the final inspection and acceptance should be developed by the consultant with information provided by the vendor. This scenario should be complete, thorough, and unique to this particular installation. It should test all features of both the hardware and the software. This means not only the handling of routing occurrences but of abnormal conditions as well. For example, if the system is supposed to tolerate power failures and be capable of performing functions while on battery backup or emergency generator, the system should be operated this way during the acceptance test.

The consultant's fifth task is *Training and Consultation*. In the bid documents he should specify levels and quantities of training to be furnished by the vendor, and he should monitor the vendor's training to ensure compliance. This training usually takes place before system acceptance. However, a second training period should occur within twelve months of system acceptance, and it should also be monitored by the consultant.

Extra Consultant Services

This portion of the contract should be defined so that both owner and consultant know what the extras are and how they will be handled. These services should be authorized in writing by the owner. Services covered would include, for example, revising previously approved planning report documents or construction documents to accommodate changes. Correction of design errors, deficiencies and omissions of the consultant would not be covered, nor would any changes necessary to bring the design development within the construction cost limit as called forth in the Feasibility Study. Any additional services made necessary by the default of the vendor are also not included and should be paid for. Services as an expert witness in a court proceeding after the warranty period of the system or any consultation service, requested by the owner, relating to this design not otherwise provided for in the contract should be paid for.

Future Consultant Services

Services required under this portion of the contract will be on problems of studies within the capacity of the consultant but unrelated to this particular facility control project. Since an indefinite span of time is covered, a mechanism for renegotiation of fee should be included.

Owner's Responsibility

This section of the contract delineates specifically what the owner is to do or what he is to provide the

consultant. The owner should designate a representative to act on his behalf. This person should not be removed from the project if at all possible. The owner should furnish project budgets and construction cost limitations, gross square footage facility requirements, budget limitations, and project schedules. If applicable, the owner should provide a complete set of mechanical and electrical drawings for areas affected by the facility control system.

The owner should be represented at the site by his representative. This does not relieve the consultant of responsibilities placed on him by the terms of his contract. This part of the contract should also contain a statement that any act or failure to act on the part of the owner shall not constitute a waiver of claim by him for any defects or deficiencies in the drawings, specifications, or design.

Construction Cost

This section assigns responsibility for maintaining adequate control throughout the design process to ensure that the construction cost limitation is not exceeded. The format and content of the cost estimate should include the major categories of work for the entire project. Each category should be detailed to show individual items of work in both quantity and unit cost for both material and labor.

The consultant should prepare a final cost estimate for submission to the owner with the completed bid documents. This estimate should be a continuation and expansion of the construction cost estimate included in the feasibility study, but should reflect all changes in design and construction cost that have occurred since the feasibility study. Provision should be made to cover the contingency of an over-budget bid. In this case, if the lowest responsive bid exceeds the final construction cost estimate by more than five percent, it should be the responsibility of the consultant to revise the design to bring the project back within the cost limit.

Compensation

This section of the contract covers how the consultant is paid (e.g., monthly) and the not-to-exceed amount for each item of service. This may be shown as follows.

Task One — Feasibility Study	$_____
Task Two — Preparation of Bid Documents	$_____
Extra Services	$_____ per hour
Future Services	$_____ per hour
	Plus travel.

The item for postage and reproduction of documents should include the number of document sets required and provide for reimbursement to the consultant for sets in excess of that number.

Termination of Agreement

If this should happen, it is best that both parties understand their responsibilities. The owner usually reserves the right to cancel any work on written notice to the consultant. In the event of cancellation, the owner should reimburse the consultant for all work completed or in progress, including drawings or specs, and whether in the possession of the owner or the consultant. The terms should include a statement that the sum paid is complete settlement of all claims for services under this contract. If the owner should then decide to complete the project, the owner should have the right to use any and all original tracings, drawings, calculations, design analysis, specifications, estimates, and other documents including bid documents prepared under the contract with the consultant. The owner should agree to credit the consultant with authorship when due, but he is not required to renew the contract.

Documents

This section of the contract should define ownership of documents. The drawings and specifications should be considered to be the property of the owner whether or not the project is constructed. The documents should not be used by the consultant for any other project without the written agreement of the owner.

While this discussion does not cover all the contractual possibilities that may arise during the planning and installation of a facility control system, any comprehensive definition assigning responsibility, accountability, and authority should thoroughly address these same areas. Failure to do so will result in spending more and buying less.

CHAPTER SEVEN

SELLING THE ENERGY MANAGEMENT SYSTEM

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An aggressive physical plant manager includes salesmanship in his management program. Most physical plant managers, however, are engineers by profession, not salesmen. This chapter provides information helpful in selling an Energy Management Program.

Two essential basic requirements of salesmanship are:

1) an understanding of the product being sold
2) a commitment to that product and its application.

Commitment is the most essential requirement in salesmanship. The product here is a microprocessor-based energy management system.

This publication presents a creative system for energy control — a system that requires commitment, planning, design, purchasing, installation, and operation. The system has been developed through creative thinking. Creative selling is required to ensure its success as a continuous operation.

The physical plant director has spent considerable time in planning for the chosen system. He must be convinced personally that the microprocessor system can save the university energy and money and that it will have tremendous fringe benefits for the university in the future.

The funding of the project is a key to its successful installation and operation. The costs for the total system should be available. The director must have alternative plans for phase installation with associated total phase costs. There must be a tentative time schedule for total as well as phase installation. The experience of the director will be a tremendous factor in determination of time schedules and plant operation funding. With this information, the selling of the energy management program is ready to be made.

Basic Selling Rules

To sell the program, a set of basic selling rules and guides are needed. The following selling guides should be adhered to:

1. *Honesty and openness with everyone; complete expression of opinion.* The director's process is so attuned to the project that he has complete overall understanding of the potential of the ultimate system. These thoughts should not be kept wrapped up. They should be shared with others in discussions and in decision-making sessions.

Sometimes the other person may not understand or agree with a procedure simply because he hasn't thought the entire idea through. The director should open up his total thought procedure with this person and explain the rationale step by step. The individual may say several times, "That's true, but have you thought of this?" Maybe this has or has not been thought of, but the reply should be honest and open. The director will suddenly find that he is exchanging ideas and thoughts that will be valuable in selling the program.

2. *Objectivity: looking at all sides: keeping an open mind to the ideas of others.* The physical plant is primarily a service-oriented operation, performing services that assist the various university schools, departments, and the community as a whole. The control and conservation of energy is a responsibility that needs participation from the university community. "There are two sides to everything." *Both* sides must be looked at very objectively as this conservation program is being sold. Objectivity will enable the physical plant

director to see the other side; cause the research and academic areas to understand Physical Plant's point of view; and give added strength to the community acceptance of the program.

3. *Tactfulness in approach.* Tact should be maintained at all times during the selling process; certainly, to the extent of "I agree, but . . . " or "You have a point; here is our thinking on this." Most participants in the discussion know and recognize the director's ability and respect it. Their only reason for raising questions is to resolve a reservation in their minds with regard to the plan or program presented. The answer given and the manner of the response can be decisive in the selling process.

4. *Positive attitude.* The maintenance of positive thoughts in all presentations, planning, discussions, and selling actions will provide a tremendous effort by others in support of the program. After all, almost everyone likes to save!

5. *Preparation of a plan; following the plan.* A master plan should be comprehensive, provide adequate consideration for future change, and should allow for expansion at minimal cost. Once the plan has been presented, the selling portion is much easier to complete if the plan is followed.

6. *Alternate plans and/or procedures on hand at all times.* Alternate plans and/or procedures must be on hand (or at least in the mind) at all times. Flexibility should be demonstrated during the selling process. It will weaken resistance to acceptance of the program.

7. *Use of available expertise on campus—faculty, staff, students. Giving proper credit for this expertise.* Early in the director's commitment he should contact those persons in the campus community who have expertise, interest, or knowledge of the computer industry. The idea should be presented to them for comment with regard to whether or not they believe a system of this type would work and what equipment could be most effectively and efficiently used to meet the needs. These individuals will have a knowledge of the latest "state of the art" in computers and can be most helpful in making recommendations for the proposed system. On one campus, the head of the computer science department became very interested in the microprocessor idea and committed a great amount of time and energy to development of the system, including system design, recommended hardware, software development, proposal evaluations, and the system implementation. He helped sell the idea to the campus by simply agreeing that the idea was possible and feasible for the campus. A contact such as this can assist tenfold in developing a system and in selling the program. This help must be recognized and proper credit should be given.

8. *Use of graphics in presentation.* Selected graphic material can be used very effectively as visual aids in presentations of the system or program. The following nine graphs can be used in sales presentations. They are self-explanatory if studied extensively.

Selling the Campus Community

The physical plant director should remember that the program should always be sold through his boss. Loaded with information and visual aids, the director must go to his boss for his selling presentation.

The key points to be included are:

1. Quality of the system
2. "State of the art" system
3. Expansion capability (buildings and software programs)
4. Independent operation of microprocessor units
5. Costs versus savings (dollars and BTUs)
6. Rate of return on investment
7. Projected installation schedule.

Concentration should focus on the many advantages of the system being purchased rather than the needed funds. A point to remember is that if the system is sold to the boss, the funds will be provided. The presentation should show the various phases of installation and how each can be operated for savings. Initial installations should be made in the areas of highest consumption where greatest savings will be realized.

Prior to the meeting, the state's energy laws should be checked. Some states provide special funds including supplemental funding. In North Carolina, for example, a law permits state agencies and institutions to expend line item funds intended for utilities if a saving can be realized by the expending of the funds.

After the presentation to the boss, program guidelines should be established through the chancellor, the president, or the board of trustees. The boss will usually assist in scheduling subsequent presentations with the administration and other campus departments and groups. There is no way to implement an energy management system without

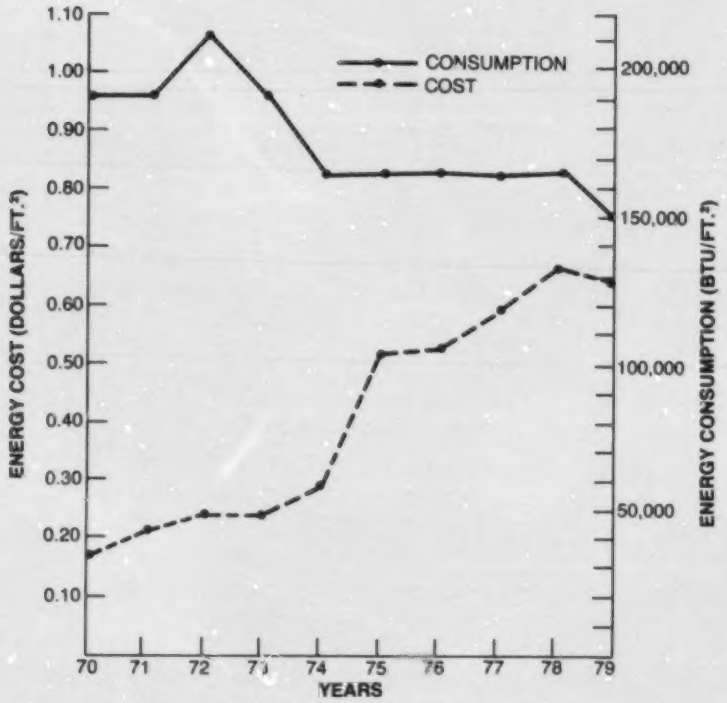

Figure 22 Energy Consumption and Cost per Square Foot

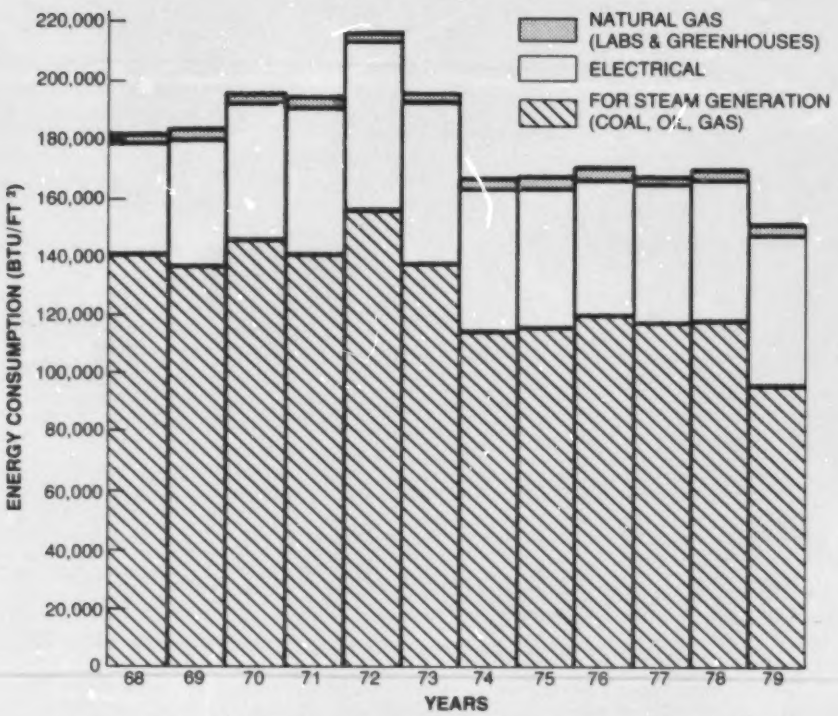

Figure 23 Total Campus Energy Consumption Per Square Foot 1968-79

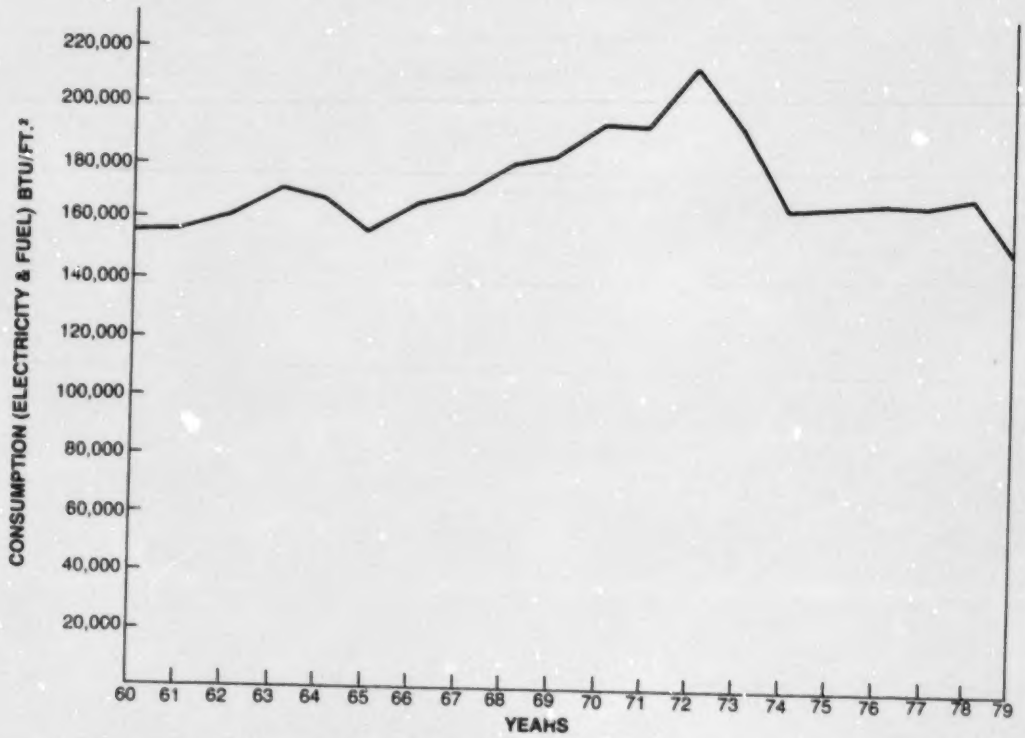

Figure 24 Total Campus Energy Consumption Per Square Foot 1960-79

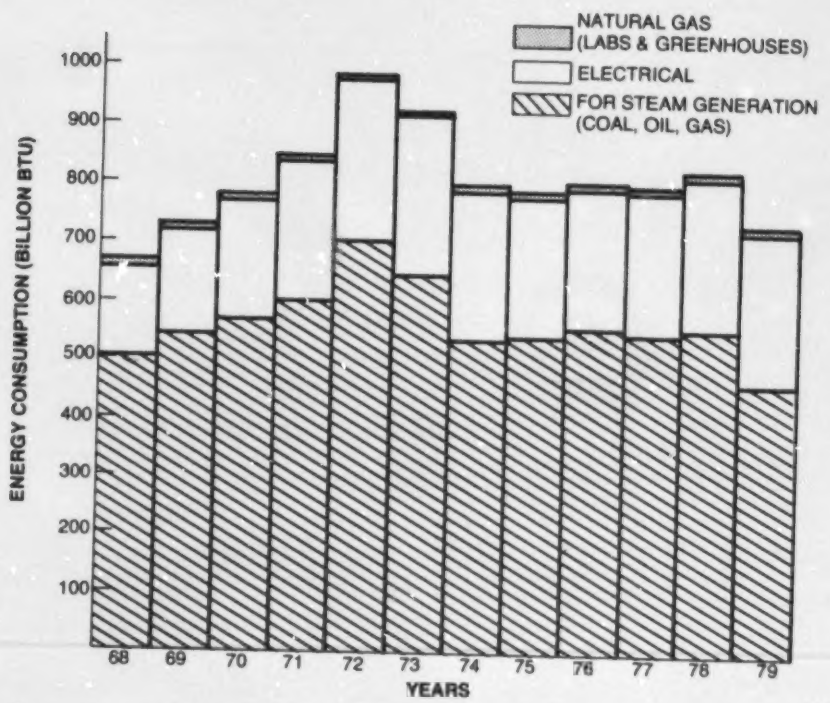

Figure 25 Total Campus Energy Consumption

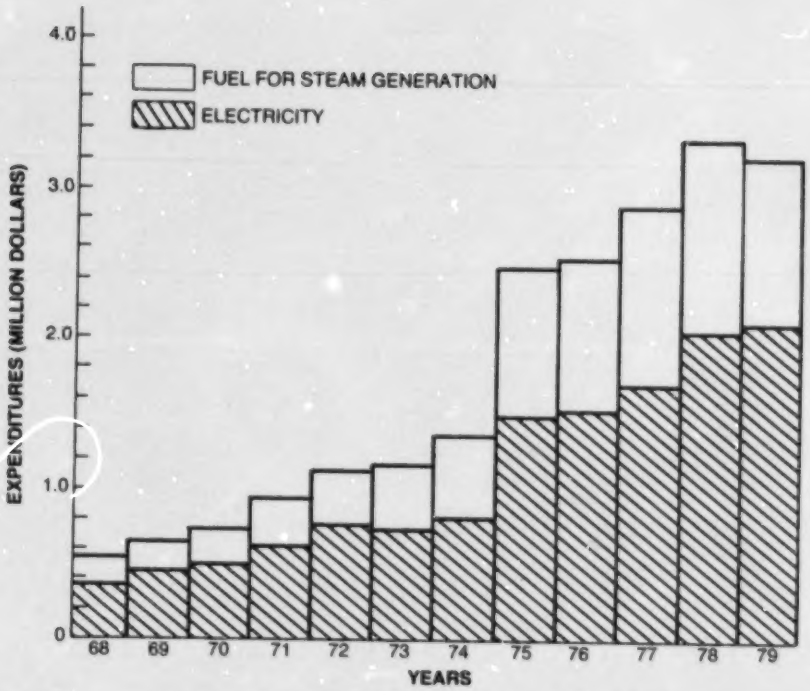

Figure 26 Total Campus Energy Expenditures

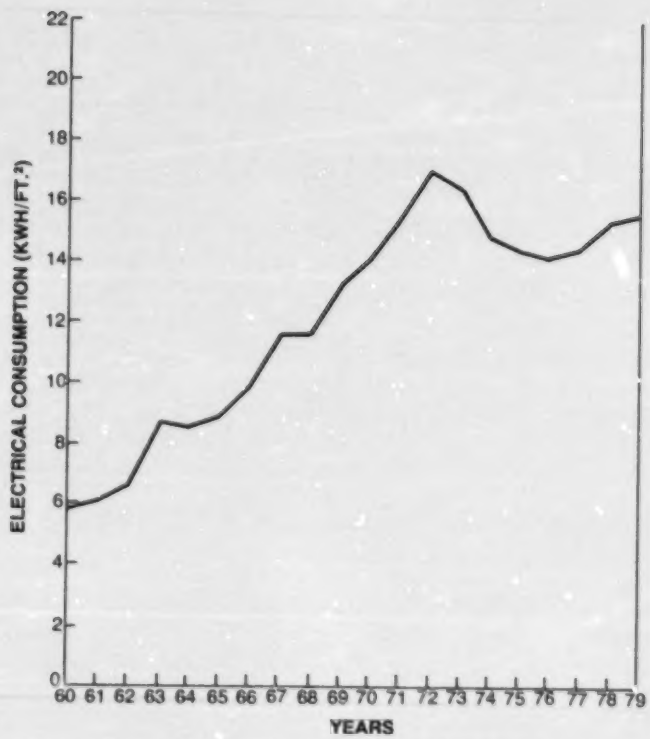

Figure 27 Campus Electrical Consumption Per Square Foot

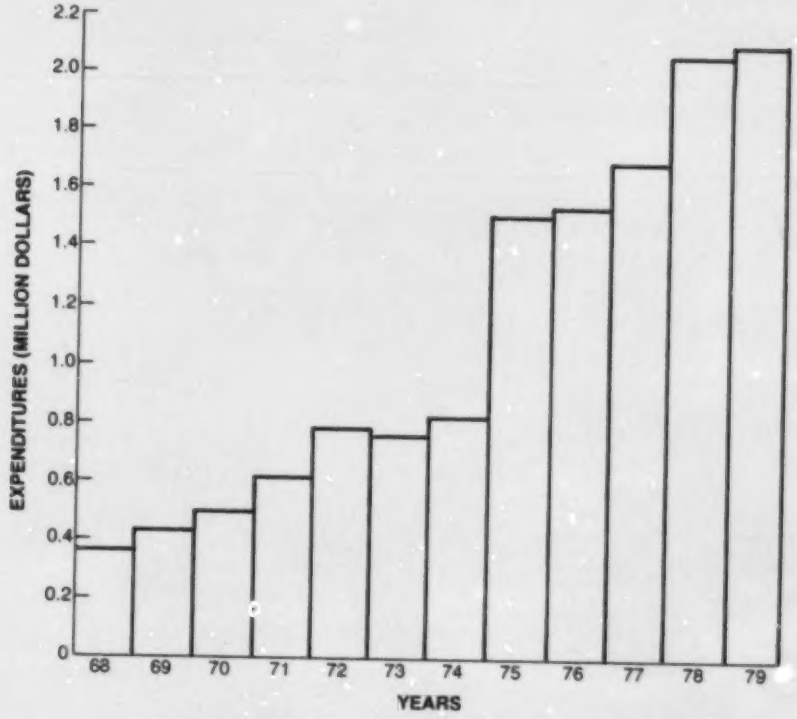

Figure 28 Total Campus Expenditures for Electricity

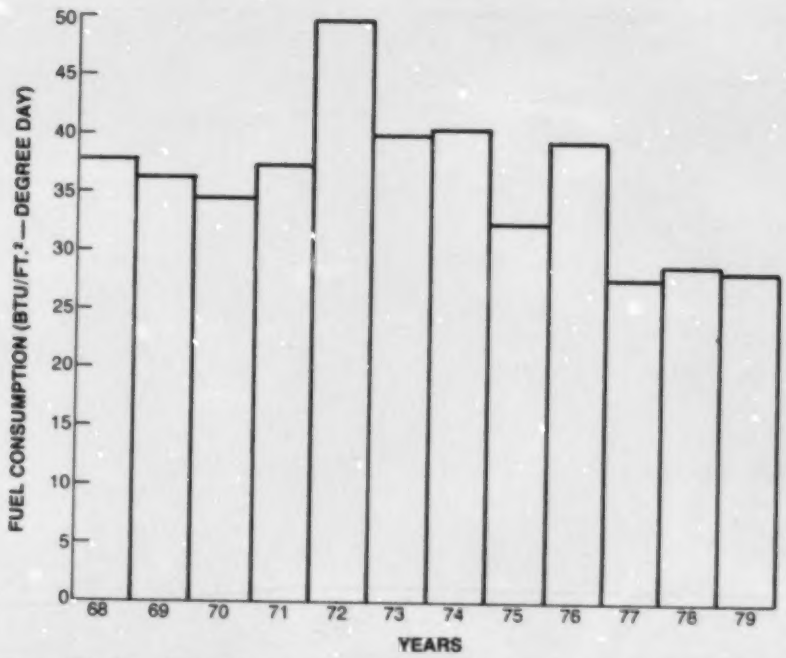

Figure 29 Steam Plant Energy Consumption Per Degree Day Per Square Foot

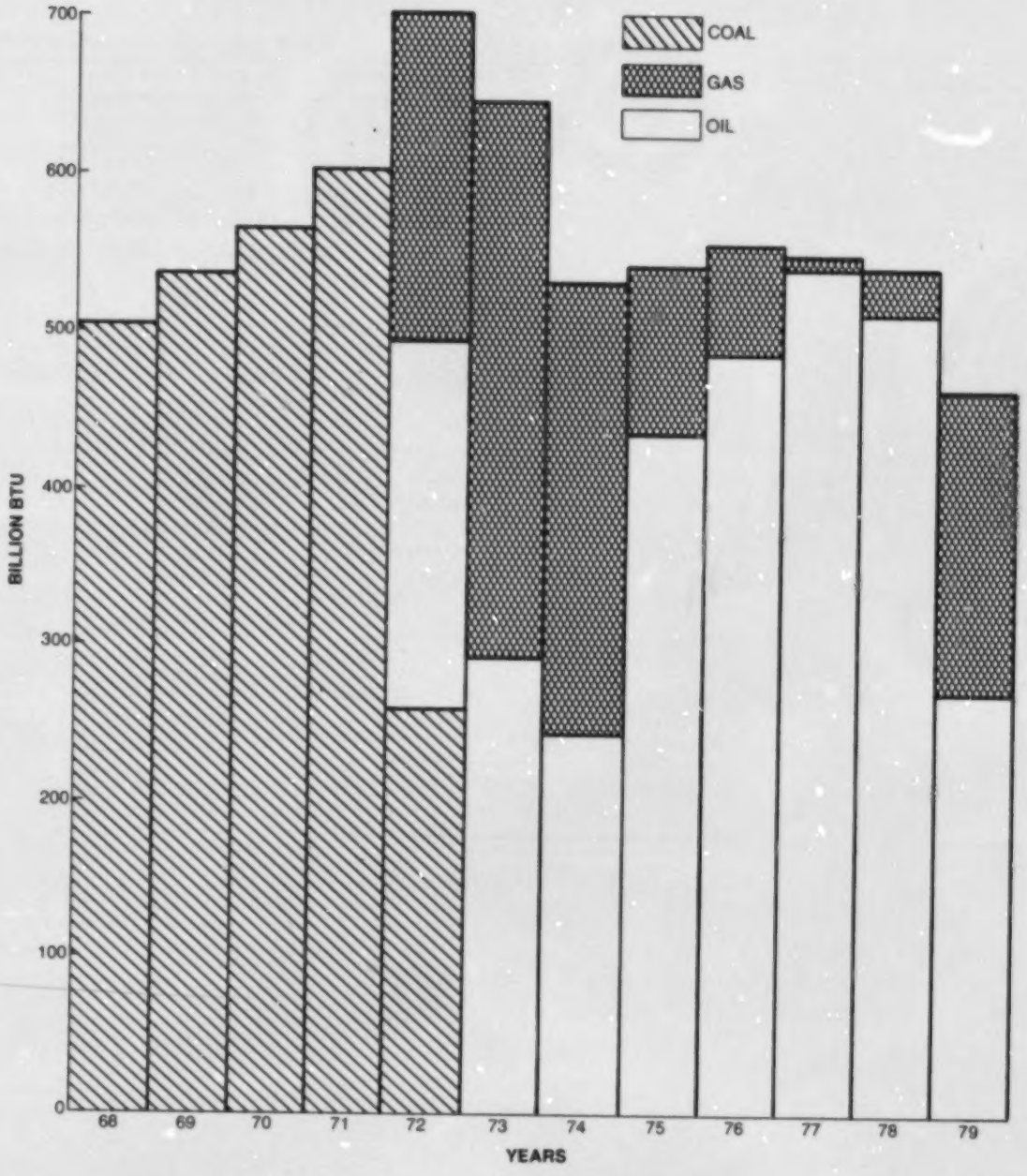

Figure 30 Steam Plant Energy Consumption

the support of the total campus community. The physical plant must be viewed as the agency that renders service of the system, but not as the agency that controls the complete program.

The following individuals or groups are likely to be involved in a project as expensive as the energy management system. These groups should be kept informed of the system's progress:

1. Staff
2. Boss
3. Chancellor
4. Board of Trustees
5. Administrative Council
6. University Community.

Some institutions use a liaison system of communication for the various departments and buildings on their campuses. These individuals represent the interests of both their department and the physical plant. It is recommended that information about the system be presented to them in a group meeting. The open group meeting encourages a freedom of expression and an interchange of ideas.

It is very simple to establish a liaison system on campus. Contact is made with each department head on campus to explain the desire to coordinate all physical plant activities with their department through one person. The department heads are usually cooperative. The liaison system is the very backbone of a public relations link to the academic community. These people will convey the energy management program to their departments.

The creative system of automated energy management through the utilization of microprocessor technology presents a challenging alternative to those proprietary systems of past years. The flexibility in application opens a new area of challenge.

APPENDIX A

Major Suppliers Of Energy Management Systems

Advanced Automation Concepts Inc., 682 Willow Ridge Dr., Marietta, Ga. 30067

Advanced Electronic Controls Inc., 818 Andrew Jackson Hwy., Huntsville, Ala. 35801

Aegis Energy Systems, 607 Airport Blvd., Doylestown, Pa. 15936

Andover Controls Corp., York & Haverhill Sts., P.O. Box 34, Andover, Mass. 01810

Applied Control Systems, 1828 Jefferson St., N.E., Minneapolis, Minn. 55418

Atlantic Energy Technologies, 55 Lake St., Nashua, N.H. 03060

Automated Logic Corp., 2675 Cumberland Pkwy, Atlanta, Ga. 30339

Automation Concepts, 2460 Walnut Ridge, Dallas, Tex. 75229

Automation Controls Corp., 672 N.E. 40th Court, Fort Lauderdale, Fla. 33334

Aviation Electronics, 2050-J Carroll Ave., Chamblee, Ga. 30341

Barber-Colman Corp., 1300 Rock St., Rockford, Ill. 61101

Bomar, Energy Management Div., 340 Royal Palm Way, Palm Beach, Fla. 33480

Chesterfield Products Inc., 511 Victor St., Saddle Brook, N.J. 07662

Compuguard Corp., 4709 Baum Blvd., Pittsburgh, Pa. 15213

Computer Sciences, 6565 Arlington Blvd., Falls Church, Va. 22046

Controlled Energy Systems Co., 6505 218th St., S.W., Suite 15, Mountlake Terrace, Wash. 98043

CSL Industries, One Century Plaza, 2029 Century Park East, Los Angeles, Calif. 90067

CS&M Systems Inc., Westover Industrial Air Park, Bldg. 7222, Chicopee, Mass. 01022

Data Sense-Valeron Corp., 32380 Edward St., Madison Heights, Mich. 48071

Delta Energetics Corp., P.O. Box 2065, Richardson, Tex. 75080

Dupont Energy Management Corp., 10730 Composite, Dallas, Tex. 75220

Dynapar Corp., 1675 Delany Road, Gurnee, Ill. 60031

Eagle Signal Energy Management Systems Inc., Div. of Gulf & Western, 30 Main St., Danbury, Conn. 06910

ECA Inc., 476 Spotswood-Englishtown Road, Jamesburg, N.J. 08831

Econics Corp., 1095 N. Tantau Ave., Cupertino, Calif. 95014

Econowatt Corp., P.O. Box 321. Pelham, N.Y. 10803

Ecotronics, 7745 E. Redfield Rd., Scottsdale, Ariz. 85260

Electronic Modules Corp., McCormick Road, P.O. Box 141, Timonium, Md. 21093

EMSCO, 2808 Longhorn Blvd., Suite 308, Austin, Tex. 78758

Enco 2000 Inc., 3162 Oakcliff Industrial St., Atlanta, Ga. 30340

Encon Systems Inc., 504-C Vandell Way, Campbell, Calif. 95008

Energy Control Systems, 6901-J Peachtree Industrial Blvd., Norcross, Ga. 30092

Energy Management Corp., 1107 Kenilworth Dr., Baltimore, Md. 21204

Energy Micro Systems Inc., 6202 Las Pas Trail, Indianapolis, Ind. 46268

Enertrol, 7418 E. Cholla Lane, Scottsdale, Ariz. 85253

Environmental Management Systems, 4350 Viewridge Ave., Suite A, San Diego, Calif. 92123

Fisher Controls Corp., 205 First Ave., Marshalltown, Iowa 50158

FlexCore, 6625 McVey Blvd., Worthington, Ohio 43085

Foxboro Corp., 38 Neponset Ave., Foxboro, Mass. 02035

Foxboro/ADEC Corp., 1421 E. Pomona, Santa Ana, Calif. 91733

Functional Devices Inc., 310 S. Union St., Russiaville, Ind. 46979

General Electric Co., P.O. Box 2913, Bloomington, Ill. 61701

Gould Inc., Modicon Div., P.O. Box 83, Shawsheen Village Stn., Andover, Mass. 01801

Honeywell Corp., Commercial Buildings Group, Honeywell Plaza, Minneapolis, Minn. 55408

Honeywell Corp., Residential Group, 10400 Yellow Circle Dr., Minnetonka, Minn. 55343

Honeywell Process Management Systems Div., Dept. 436 PW, Fort Washington, Pa. 19034

Hughes Aircraft, Microelectronic Products Div., 2601 Campus Dr., Irvine, Calif. 92715

IBM, General Systems Div., P.O. Box 2150, Atlanta, Ga. 30301

Intelligent Terminals Ltd., One Waters Park Dr., Suite 104, San Mateo, Calif. 94403

Interactive Systems Inc., 3980 Varsity Dr., Ann Arbor, Mich. 48104

Interface Systems, 4800 W. 34th St., Suite 8, Houston, Tex. 77092

International Energy Conservation Systems Inc., Suite 100, Arado West, 5600 Roswell Road, N.E., Atlanta, Ga. 30342

International Energy Management Corp., a Schindler-Haughton Div., 671 Spencer St., Toledo, Ohio 43609

J&C Lamb Corp., 2420 Jackson Ave., Long Island City, N.Y. 11101

Johnson Controls Inc., 507 E. Michigan St., Milwaukee, Wis. 53201

KVB Inc., 17332 Irvine Blvd., Tustin, Calif. 92680

Leeds & Northrup, Sumneytown Pike, North Wales, Pa. 19458

Leland Energy Corp., 2101 McKinney Ave., Dallas, Tex. 75201

LEE, Control Systems Industries, 2920 San Ysidro Way, Santa Clara, Calif. 95051

Management Improvement Corp. of America, 617 Morehead Ave., Durham, N.C. 27707

Margaux Controls, 2302 Walsh Ave., Santa Clara, Calif. 95050

Mart Con Inc., 904 S. Alta Vista, Monrovia, Calif. 91016

McQuay Group, McQuay-Perfex Inc., 13600 Industrial Park Blvd., P.O. Box 1551, Minneapolis, Minn. 55440

MicroControl Systems Inc., 6579 N. Sidney Place, Milwaukee, Wis. 53209

National Energy Corp., 1795 Williston Road, South Burlington, Vt. 05401

Pacific Technology Inc., 235 Airport Way, Renton, Wash. 98055

Power Control Products, P.O. Box 10013, Clearwater, Fla. 33517

Professional Resources Technology, 504-E Vandell Way, Bldg. E, Campbell, Calif. 95008

Radix II Inc., 4588 Beech Road, Marlow Heights, Md. 20031

Robertshaw Controls Co., Controls Systems Div., 1800 Glenside Dr., Richmond, Va. 23226

Scientific Atlanta Inc., 3845 Pleasantdale Road, Atlanta, Ga. 30340

Scientific Controls Corp., 4520 Massachusetts Ave., Orlando, Fla. 32800

Sentinel-Trane Electronics Corp., 1306 W. County Road, F., St. Paul, Minn. 55112

Sentinel Energy Controls, 8 Blanchard Road, Burlington, Mass. 01913

Solid State Systems Inc., 1990 Delk Industrial Blvd., Marietta, Ga. 30062

Square D Co., P.O. Box 472, Milwaukee, Wis. 53201

Surgeonics, 155 Kisco Ave., Kisco, N.Y. 10549

Systems Technology Corp., 18845 W. McNichols, Detroit, Mich. 48219

Tano Corp., 4301 Poche Court W., New Orleans, La. 70129

Tech-S Inc., 12997 Merriman Road, Livonia, Mich. 48150

Texas Controls Inc., P.O. Box 59459, 13735 Omega Dr., Dallas, Tex. 75229

Tour & Anderson Inc., P.O. Box 2337, 625 Glenbrook Road, Stamford, Conn. 06906

Trimax Controls Inc., 1180 Miraloma Way, Sunnyvale, Calif. 94086

Valley Industries Inc., P.O. Box 22146, Knoxville, Tenn. 37922

Vertrex Corp., 808 106th, N.E., Bellevue, Wash. 98004

Wackenhut Corp., 3280 Ponce De Leon Blvd., Coral Gables, Fla. 33134

Watt Master, U.S.A., 116 E. South St., South Bend, Ind. 46601

Weltronics Co, 495 Holley St., Clare, Mich. 48617

Westinghouse Electric Corp., Computer Instrumentation Div., 1200 W. Colonial Dr., Orlando, Fla. 32804

Westinghouse Electric Corp., Industrial Systems Div., 200 Beta Dr., Pittsburgh, Pa. 15238

Westinghouse Electric Corp., Numalogic Div., Madison Heights, Mich. 48071

Xencon, 150 Mitchell Blvd., San Rafael, Calif. 94903

This list of suppliers of energy management systems represents all those known to Energy User News at this time. It should not be construed as complete. Any additions or corrections should be brought to the attention of the editor.

List courtesy of *Energy User News*, 7 E. 12th Street, New York, N.Y. 10003.

APPENDIX B

Microprocessor Suppliers

Advanced Micro Devices, Inc., 901 Thompson Place, Sunnyvale, California 94086. Telephone (408) 732-2400.

American Microsystems, Inc., 3800 Homestead Road, Santa Clara, California 95051. Telephone (408) 246-0330.

Data General Corporation, Route 9, Westboro, Massachusetts 01581. Telephone (617) 485-9100.

Essex-Semiconductor (Wire Assembly Division), 301 Alpha Drive, Pittsburgh, Pennsylvania 15238. Telephone (412) 782-0200.

Fairchild Semiconductor Components, MOS Division, 464 Ellis Street, Mountain View, California 94042. Telephone (415) 962-3414.

General Instrument Corporation (Microelectronics), 600 West John Street, Hicksville, New York 11802. Telephone (516) 733-3000.

Harris Semiconductor, P.O. Box 883, Melvourne, Florida 32901. Telephone (305) 724-7660.

Hughes Microelectronic Products Division, 500 Superior Avenue, Newport Beach, California 92663. Telephone (714) 759-2411.

Intel Corporation. 3065 Bowers Avenue, Santa Clara, California 95051. Telephone (408) 987-8080.

Intersil, Inc., 10900 North Tantau Avenue, Cupertino, California 95014. Telephone (408) 257-5450.

Monolithic Memories, Inc., 1165 E. Arques Avenue, Sunnyvale, California 94086. Telephone (408) 739-3535.

MOS Technology, Inc., 950 Rittenhouse Road, Norristown, Pennsylvania 19401. Telephone (215) 666-7950.

Mostek Corporation, 1215 West Crosby Road, Carrolton, Texas 75006. Telephone (214) 242-0444.

Motorola Semiconductor Products, Inc., 3501 Ed Bluestein Blvd., Austin, Texas 78721. Telephone (512) 928-2600.

National Semiconductor Corporation, 2900 Semiconductor Drive, Santa Clara, California 95051. Telephone (408) 737-5000.

NEC Microcomputers, Inc., Five Militia Drive, Lexington, Massachusetts 02173. Telephone (617) 862-6410.

Raytheon Semiconductor, 350 Ellis Street, Mountain View, California 94042. Telephone (415) 868-9211.

RCA Solid State Division, 17331 Irvine Blvd., Tustin, California 92680. Telephone (714) 832-5302.

Rockwell International Microcomputer Product Engineering, Strategic Systems Division, 3370 Miraloma Avenue, Anaheim, California 92803.

Scientific Micro Systems, 520 Clyde Avenue, Mountain View, California 94043. Telephone (415) 964-5700.

Signetics Corporation, 811 East Arques Avenue, P. O. Box 9052, Sunnyvale, California 94086. Telephone (408) 739-7700

Solid State Scientific, Inc., Montgomeryville, Pennsylvania 18936. Telephone (215) 855-8400.

Synertek Corporation, 3050 Coronado Drive, Santa Clara, California 95051. Telephone (408) 984-8900.

Texas Instruments, Inc., 8600 Commerce Park, Houston, Texas 77036. Telephone (713) 491-5115.

Western Digital, 3128 Red Hill Avenue, Newport Beach, California 92663. Telephone (714) 557-3550.

Zilog, 10460 Bubb Road, Cupertino, California 95014. Telephone (408) 446-4666.

GLOSSARY

Access Time (microseconds/word) — The actual elapsed time between the central processing units request for data and the time that is read.

Add Time (microseconds) — A first level indication of fixed-point arithmetic speeds. In general, the indicated add times are the times required to retrieve a one-word operand from main storage and add it to another operand already contained in an accumulator with no indexing or indirect addressing.

Algorithm — A rule of procedure for solving a recurrent mathematical problem.

Analog — A continuously varying signal value (i.e. temperature, current, pressure).

Application Software Language — See Controls Software Language.

Architecture —The general organization and structure of hardware and software.

ASCII Code (American Standard Code for Information Interchange) — Any eight bit coded character set to be used for the general interchange of information among information processing systems, communication systems and associated equipment.

Assembler — Utility program which translates assembly language source code into the machine-executable object code.

Assembly Language — A mnemonic computer language representing the machine binary structures used to program and manage the operations of a computer.

Asynchronous Computer — An automatic digital computer in which each operation starts as a result of a signal generated by the completion of the previous event or operation, or by the availability of the parts of the computer required by the next event or operation.

Battery backup — A feature which causes the computer to use standby battery power and record the contents of memory on a system disk if a power failure occurs.

Baud — A unit of transmission speed equal to the number of discrete conditions or signal events (bits) per second. (BITS/SEC).

BCD (Binary Coded Decimal) — A system of number representation that indicates each decimal digit of a number as a four bit binary number.

Bipolar Storage — Bipolar, a type of transistor-transistor logic which offers higher speed at the expense of more space and greater power consumption.

Bit — An acronym for a binary digit. A bit is the smallest divisible unit of information having only two values; one or zero.

Bit Error Rate — The number of incorrect or erroneous bits divided by the total number (correct plus incorrect) over some stipulated period of time.

Bootstrap — A technique or device designed to bring a computer into a desired state by means of its own action.

bps — Bits per second.

Break Point — A point in a program where an instruction or other condition enables a programmer to interrupt the running of a program by external intervention or a monitor routine. Used in debugging.

Buffer — A device which stores information temporarily during data transfer.

Byte — A group of eight bits.

Call — A term used to designate the software procedure by which software control is transferred to a callable subroutine.

Callable — A subroutine module to which software control can be transferred.

Cathode Ray Tube (CRT) — An electron beam tube in which the beam is focused to a small cross section on a luminescent screen and varied in position and intensity to produce a visible pattern.

Central Control Unit (CCU) — A process control digital computer that includes a CPU, central memory and an I/O bus.

Central Communications Controller (CCC) — The subsystem of the MCR performing data gathering and dissemination from and to the FIDs as well as providing limited backup to the CCU.

Central Memory — Core or semiconductor memory communicating directly with a central processing unit.

Central Processing Unit (CPU) — The portion of the computer (e.g. CCU, FID, CCC) that performs the interpretation and execution of instructions. It does not include memory or I/O.

CLT — Communication Link Termination.

Command Line Mnemonic (CLM) **Interpreter** (CLMI) — A set of fixed, simplified English commands designed to assist operators unfamiliar with computer technology in operating the EMCS.

Compiler/Interpreter — System software used for converting high level language instructions into the machine language of the computer.

Controls — Devices which govern the performance of a system.

Controls Configuration Modification — The ability to modify, relocate, reprogram or combine new and existing modules to respond to changing system functional requirements without disrupting normal operation.

Control Sequence — Equipment operating order established upon a correlated set of data environment conditions.

Controls Software Language — A language used to manage the operations of a computer. Two commonly used languages are *Assembly* which is a low-level computer language and *Fortran* which is an English like language used for technical application.

Control Storage — An indication of the microprogrammability of the minicomputer.

Core Resident — Core resident specifies a program which currently resides in central memory (and may thus be considered active) as opposed to programs residing on the disk which must be loaded into central memory for execution.

Core Storage — Magnetic core is fast, flexible and reliable. Semi-conductors have higher performance at lower cost however, cycle time, microseconds/word is the minimum time interval that must elapse between the starts of two successive accesses to any one storage location.

CRT — Cathode Ray Tube.

CPU — Central Processing Unit — The portion of the computer that performs the interpretation and execution of instructions. It does not include memory, input or output.

CRT Terminal — A peripheral device comprised of a CRT, keyboard and associated electronics enabling it to communicate with the computer system.

Cycle Time — In microseconds per word for central memory is the minimum time interval that must elapse between the starts of two successive accesses to any one storage location.

Data Communications Equipment — A device for transmitting digital information to and from any other system.

Data Communications Interface — The minicomputer's capabilities to send and receive data over a common-carrier communications link.

Data Environment (DE) — The sensors and control devices connected to a single FID. Extends to equipment and systems sampled or affected by these sensors or control devices.

dbm — A measure of absolute power values. Zero dbm equals one milliwatt.

Debug — The procedure of detecting and correcting errors in a program.

Decibel (db) — The standard unit for expressing transmission gain or loss utilizing logrithmic power and voltage ratios.

Demand — The term used to describe the maximum rate of use of electrical energy averaged over a specific interval of time and usually expressed in kilowatts.

Demultiplexer — A device to separate two or more signals that were previously combined by a compatible multiplexer and are transmitted over a single channel.

Diagnostic Program — Machine-executable instructions used to detect and isolate component malfunctions.

Digital Signals — A discontinuous signal, the various states of which are discrete intervals apart. In radix 2 the signal is either on or off (zero or one) and is referred to as binary.

Direct Digital Control (DDC) — Sensing and control of processes directly with digital control electronics (see Supervisory Control).

Direct Memory Access (DMA) — Provision for transfer of data blocks directly between central memory and an external device interface.

Disk Memory — A bulk storage, random access device for storing digitally coded information. Usually constructed of a thin rotating circular plate having a magnetizable coating, a read/write head(s) and associated control equipment.

Disk Pack/Cartridge Drives — Signifies whether one or the other, or both types of devices can be interfaced to the system and the minimum and maximum on-line capacities available.

Distributed Processing System — A system of multiple, programmable processors each performing its own task, yet working together as a complete system to solve still other tasks.

Driver/Handler — Software which manages input/output to and from a given peripheral device.

Drum Fixed Head Disk Storage — The availability of a drum or fixed head disk drive and the minimum and maximum on-line capacities that are offered. The indicated maximum storage capacities are shown in thousands (K) or million (M) of bytes.

Duplex — A method of operation of a communications line in which each terminal can simultaneously transmit and receive.

EMCS — Energy Monitoring and Control System.

Error Correction — Involves appending five or six check bits to each word or memory. The check bits and special algorithms allow a system to detect and correct single-bit errors and to detect a fair proportion of the multiple bit errors.

Executive Software — Programs which control the priority of signal processing, keep track of real time, direct information in and out of memory, control the operation of all associated hardware and encode/decode incoming and outgoing signals. It is essential that these programs include the orderly shutdown of the computer in the event of power failure to ensure that all information is safely stored in permanent memory before power is lost.

Failsafe Condition — A condition that does not lend destruction or failure to the existing control system or equipment.

FID Failure — Loss of control of the data environment due to FID power failure or diagnostics within the FID causing its shutdown. Further, failure of protective devices such as fuses, shall be included in this definition.

Field Interface Device (FID) — A small, intelligent hardware device containing software which implements the distributed processing aspects of operation with the central computer as well as maintaining effective control of field control loops in the absence of higher level influence. Operating constants are changed by down-line loading from the CCC as well as from within the FID.

Fixed-Point Operand Length, Bits — The Fixed-point operand length, bits signifies "extended precision" which enables the minicomputer to handle arithmetic operands two or more words in length. For most minicomputers, however, the fixed-point operand length bits is the same as the word lengths.

Floppy Disk — Sometimes referred to as a "diskette" is a flexible mylar disk, about 8 inches in diameter permanently housed in a plastic envelope which serves as an input/output random-access storage medium.

Floppy Disk (Diskette) Drives — Indication of whether floppy disks are available for a particular minicomputer and the minimum and maximum on-line capacities that are offered.

Foreground/Background — Concurrent background programs may be run without interruption of the running foreground program.

FORTRAN (FORmula TRANslator) — A high-level, English-like programming language used for technical applications.

Function Keys — Keys which, when depressed, send more than one character and are interpreted by the computer as a specific command.

Half Duplex — A method of operation of a communications line in which each terminal can transmit and receive, but not simultaneously.

Hardware — The EMCS equipment such as CPU, peripherals etc. as opposed to software.

Hardware Byte Manipulation — The ability to conveniently process information expressed in 8-bit character codes.

Hardware Floating Point — Refers to hard wired capability to perform floating decimal arithmetic. Where available, these facilities can dramatically reduce the execution times for certain programs by eliminating the need for time consuming floating-point subroutines.

Hardware Multiply/Divide — Refers to hard wired logic built into the machine for multiplication and division calculations. When no hardware facilities are present, multiplication and division must be performed by means of programmed subroutines at a significant reduction in execution speeds.

Hardware Vectored Interrupts — Hardware feature which allows the CPU to directly determine the identity of an interrupting device and to automatically transfer control to a program which will service the interrupt.

High Level Language — A high level language in a problem-oriented or procedure-oriented programming language allowing the programmer to express operations in a less direct form than machine oriented or mnemonic languages.

Instruction Length, Bits — One word in most computers, but some are capable of using instructions which are two or more words in length.

Interactive — Computer operation, control programming, changing etc. performed by an operator with the machine prompting or otherwise assisting these endeavors while continuously performing all other tasks as scheduled.

Interrupt — An externally generated signal requesting that current operations be suspended to perform more important tasks.

I/O — Input/Output.

I/O Bus — The connection through which data is transmitted and received from peripheral devices interacting with the processor.

K — (as in 64K words) 1K = 1024.

Large Scale Integration (LSI) — Manufacturing technology in micro-miniaturization, called integrated circuit, in which a complexity of over 100 logic gates are packaged on one small "chip."

Line Driver — A hardware element which enables digital signals to be directly transmitted over circuits to other devices some distance away.

Loader — A program used to prepare the computer and store other programs into memory locations in preparation for machine execution.

Machine Language — A computer language at the binary "zero" and "one" (digital) level that the computer actually understands when a program is executed.

Macro — A single programming symbolic instruction that generates multiple assembly language instructions.

Magnetic Tape Cassettes and Cartridges — Easily transportable file storage systems on which data is relatively free from damage. However, transfer rates are slower and on-line storage is reduced over other systems. Transfer rates are indicated in characters per second (cps) or thousands of bytes per second (KBS).

Master Control Room (MCR) — The central facility containing the operator consule, CCU, CCC, and related equipment for control and supervision of the complete EMCS.

Maximum I/O Rate, Words/Sec — A measure of each computer's potential ability to transfer data to and from peripheral devices or other external sources.

Medium Scale Integration (MSI) — An integrated circuit containing 12 to 100 logic gates.

Memory Modules — Increments of memory, usually 4K, 8K, 16K, words in length.

Microcomputer — A small computer using microprocessors.

Minicomputer — A small computer usually incorporating miniaturization of hardware circuits.

Mnemonic — A symbolic representation or abbreviation of computer functions in programming designed to help operators remember and understand.

Modem (Modular/Demodulator) — A hardware device used for changing digital information to and from an analog form to allow transmission over voice grade circuits.

MOS Storage — Metal oxide semiconductor. MOS is more popular because of compactness and price.

Multiplexer (MUX) — A device which combines multiple signals on one transmission media.

Multi-Programming Executive — A program designed to execute multi-tasks concurrently within the machine under the management of a real-time operating system.

Multi-Tasking — More than one program may be resident in the central memory and executed concurrently within the computer under the management of the operating system.

Multi-User — Multiple operations from multiple input/output devices (e.g., CRT's, keyboard printers, modems) are able to concurrently issue commands to the running programs.

Nonvolatile Memory — A memory which retains information in the absence of applied power.

Number of Accumulators — A register that holds one operand and permits various arithmetic and logical operations to be performed upon it.

Number of Addressing Modes — Refers to the number of different types of additional addressing modes other than the direct mode available to the user.

Number of Directly Addressable Words — An important characteristic that limits the number of bits that can be assigned to hold the address port of each instruction.

Number of External Interrupt Levels — The number of different external devices whose interrupt signals can be identified by the processor.

Number of Index Registers — An indication of a computer's programming flexibility and efficiency.

Paper Tape Input — An indication if a paper tape reader is offered.

Parity Checking — A feature which permits detection of most, though not all, read and write errors.

Predictor/Corrector Program — Continuous prediction of a future value and subsequent correction based on actual measurements.

Process Automation — Process control without human intervention.

Process Control — The collective functions performed by the equipment which is to control a variable.

Prompt/Response Sequence — Man-Machine dialogue by which the computer asks questions and requests responses from the operator.

Punched Card Input — An indication if a punched card reader is offered, and its speed in cards per minute (cpm).

Random Access Memory (RAM) — A volatile semiconductor memory that digital information can be written into or read out of any memory location.

Real-Time — A situation in which a computer monitors, evaluates, reaches decisions and effects controls within the relaxation time of the fastest loop or specified response time.

Register — A digital-computer device capable of retaining information, often that contained in a small subset of the aggregate information.

ROM, PROM, EPROM — Read-Only-Memory, Programmable-Read-Only-Memory, Erasable-Programmable-Read-Only-Memory. All are nonvolatile semiconductor memory.

RTDOS/E — Real-Time Disk Operating System/Executive.

Schedule — A group of equipment to be controlled or a group of sensors to be read dependent upon one or more similar conditions or the same algorithim or program.

Selective Generation — Where the management of input/output is restricted to selected peripherals.

Sensors — Devices used to detect or measure physical phenomena.

Serial Printer — A character-at-a-time printer.

Single Stepping — Procedure by which the next binary instruction in a core resident program is executed by depressing a switch.

Snapshot — Picture of the instantaneous status and state of a system.

Software — A term used to describe all programs whether in machine, assembly, or high-level language.

Source Code — A term used to describe mnemonic, English-like code (as opposed to machine code) and high level programmer developed code.

Stand-Alone — A term used to designate a device or system which can perform its function totally independent of any other device or system.

Supervisory Control — Separate (and usually remote) control and monitoring of local control loops. (see Direct Digital Control).

Transmission Media — The link (telephone pairs, coaxial cables, radio frequency (RF), fiberoptics) that interconnects EMCS equipment located in separate buildings, not including interconnection within a building.

True Digital — A representation of any value by symmetric digits, used to form fixed length words.

Vectored Interrupt — A function that allows the computer to be interrupted to solve a problem, the computer "vectors" to a memory location containing the program designed to respond to the interrupt.

Word — A set of binary bits handled by the computer as the primary unit of information.

Zone — An area composed of a building, a portion of a building, or a group of buildings affected by a single device or piece of equipment.

NOTES

Introduction

[1]*Microprocessor Based Energy Controls*, Monograph No. 16d, National Electrical Contractors Association (Washington, D.C.: 1979), p. 1.

[2]"*Microprocessor Based Energy Controls*," 12/79 Electrical Design Library published by National Electrical Contractors Association for architects, engineers, and other building design professionals. EDL is distributed by NECA chapters throughout the country.

Chapter Four — Types of Control Systems

[3]*ASHRAE Handbook and Product Directory 1976 Systems*, published by the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (New York, N.Y.: 1976), p. 34.10. "Reprinted with permission from the 1976 Systems Volume, ASHRAE Handbook and Product Directory."

[4]"Microprocessor," p. 3.

Chapter Five — Sources and Costs

[5]*Energy Monitoring and Control System (EMCS)*, Publication No. 78 MR 423, Naval Facilities Engineering Command (Port Hueneme, California, 1979), pp. 17-19.

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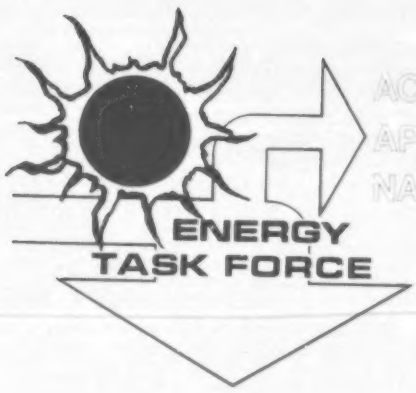

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